NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

RAPTOR: AN EMPIRICAL EVALUATION OF AN ECOLOGICAL INTERFACE DESIGNED TO INCREASE WARFIGHTER COGNITIVE PERFORMANCE

by

Daniel Shane Hall

June 2009

Thesis Advisor:	Lawrence G. Shattuck
Second Reader:	Nita Lewis Miller

Approved for public release; public distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2009	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. Title And Subtitle Raptor: An Empirical Evaluation of an Ecological Interface Designed to Increase Warfighter Cognitive Performance	**5. FUNDING NUMBERS**
6. AUTHOR(S) Daniel Shane Hall	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

A prototype interface was developed to support military practitioners with enhanced levels of situation awareness and better decision making as they conduct command and control activities during tactical operations. A laboratory experiment was conducted to evaluate the capability of this interface's cognitive systems engineering and ecological interface design principles to support critical activities (i.e., assess anticipated enemy actions on friendly force operations). Qualitative tactical simulations and an alternative interface (an experimental version of an existing U.S. Army interface) were developed. Participants were blocked against one interface and provided estimates of perceived cognitive workload while collecting, integrating, and reporting various forms of friendly and enemy force information during two realistic tactical scenarios. The results suggested that the prototype interface produced significantly better performance in six out of seven statistical comparisons examined. The cognitive systems engineering and ecological interface design strategy was very effective in this experimental context. The potential for this design to be useful for other complex work domains is explored. Actual or potential applications of this study include both specific interface design strategies for military command and control and general interface design principles for civil transportation domains.

14. SUBJECT TERMS Cognitive Systems Engineering, Ecological Interface Design, Direct Perception, Direct Manipulation, Situation Awareness, Decision Making, Cognitive Workload, DMSC, C-SWAT	**15. NUMBER OF PAGES** 197
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)

Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

RAPTOR: AN EMPIRICAL EVALUATION OF AN ECOLOGICAL INTERFACE DESIGNED TO INCREASE WARFIGHTER COGNITIVE PERFORMANCE

Daniel Shane Hall
Major, United States Army
B.A., Texas A&M University, 1998

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN HUMAN SYSTEMS INTEGRATION

from the

NAVAL POSTGRADUATE SCHOOL

June 2009

Author: Daniel S. Hall

Approved by: Lawrence G. Shattuck, PhD
Thesis Advisor

Nita Lewis Miller, PhD
Second Reader

Robert F. Dell, PhD
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

A prototype interface was developed to support military practitioners with enhanced levels of situation awareness and better decision making as they conduct command and control activities during tactical operations. A laboratory experiment was conducted to evaluate the capability of this interface's cognitive systems engineering and ecological interface design principles to support critical activities (i.e., assess anticipated enemy actions on friendly force operations). Qualitative tactical simulations and an alternative interface (an experimental version of an existing U.S. Army interface) were developed. Participants were blocked against one interface and provided estimates of perceived levels of cognitive workload while collecting, integrating, and reporting various forms of friendly and enemy force information during two realistic tactical scenarios. The results suggested that the prototype interface produced significantly better performance in six out of seven statistical comparisons examined. The cognitive systems engineering and ecological interface design strategy was very effective in this experimental context. The potential for this design to be useful for other complex work domains is explored. Actual or potential applications of this study include both specific interface design strategies for military command and control and general interface design principles for civil transportation work domains.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ABCS	United States Army Battle Command System
API	Application Program Interface
BOS	Battlefield Operating Systems
C^2	Command and Control
C4I	Command, Control, Communications, Computer Applications & Intelligence
CCIR	Commander Critical Information Requirements
COA	Course of Action
COP	Common Operating Picture
CSE	Cognitive Systems Engineering
C-SWAT	Continuous Subjective Workload Assessment Technique
DDD 4.0	Distributed Dynamic Decision Making
DMSC	Dynamic Model of Situated Cognition
DP	Decision Point
EID	Ecological Interface Design
FBCB2	Force XXI Battle Command, Brigade and Below
FFIR	Friendly Force Information Requirements
HSI	Human Systems Integration
HSP	Human System Performance
IM	Information Management
INFOSYS	Information Systems
MDMP	Military Decision Making Process
NCO	Network-Centric Operations
NDM	Naturalistic Decision Making
NPS	Naval Postgraduate School
PCO	Platform-Centric Operations
PIR	Priority Intelligence Requirements
RAPTOR	Representation Aiding Portrayal of Tactical Operations Resources
RFI	Request for Information
RI	Relevant Information
RPD	Recognition Primed Decision Making
SA	Situational Awareness
SRK	Skills, Rules, Knowledge Taxonomy
TOC	Tactical Operation Center
TRACE	Tactical Rating of Awareness for Combat Environments

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Information is vital for success during war. Since the turn of the twentieth century, information technology has continued to advance at an exponential rate, enabling commanders to take advantage of the speed, range, and lethality of modern weaponry. Information technology advancements also make warfare more complex. Since the inception of the Force XXI modernization program, the U.S. Army has fielded numerous interfaces to leverage the capabilities of digital information systems during the command and control of tactical operations. In reality, many of these information technologies have given little consideration to the role of the human in the design or implementation of the systems. This failure to recognize humans as the critical nodes within information system designs ultimately degrade total system performance and further complicate command.

Ultimately, success in enhancing decision-maker performance relies on the integration of human cognition and technological capability. This reliance on both human and machine agents strongly suggests a Human Systems Integration approach, which strives to implement people as the key elements within the "system of systems" architecture by assisting in system designs that support human limitations and enhance human strengths.

Information complexity in itself is not a problem, given meaningful information is presented in a coherent and structured manner. The essential notion being that in order for information system technologies to improve total system performance and effectiveness, information must be constructed into representations that exploit the inherent pattern-recognition capabilities of the human, while also decreasing reliance on limited-capacity resources. Accordingly, this study explores the effectiveness of a prototype interface (RAPTOR) designed to be used in command and control during tactical operations. The extent to which warfighter performance is enhanced by the cognitive systems engineering approach and ecological interface design principles used to develop RAPTOR are made explicit.

During this study, a laboratory experiment was conducted to evaluate the capability of the interface to support military practitioners as they conducted critical command and control activities (i.e., assess anticipated enemy actions on friendly force operations) during tactical operations. U.S. Army officers with previous combat experience in Operation Iraqi Freedom and/or Operation Enduring Freedom served as participants. Two qualitative tactical simulations and an alternative interface (an experimental version of an existing U.S. Army interface) were developed. Participants were blocked against one interface and provided estimates of perceived cognitive workload while collecting, integrating, and reporting various forms of friendly and enemy force information during the tactical simulations.

The results suggested that the prototype interface produced significantly better performance in six out of seven statistical comparisons examined. The cognitive systems engineering and ecological interface design strategy was very effective in this experimental context. The results also demonstrate the potential for this design strategy to be useful for other complex work domains. Actual or potential applications of this study include both specific interface design strategies for military command and control and general interface design principles for civil transportation work domains.

In conclusion, researchers believe results from this study achieved the primary purpose of assisting the U.S. Army in its efforts to develop advanced C^2 interfaces that account for human capabilities and limitations.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to several individuals whose constant guidance, counsel, and encouragement were instrumental in my success during this 12-month project. First, I will forever be deeply appreciative for the mentorship and expert advice Dr. Lawrence G. Shattuck, thesis advisor, bestowed upon me throughout the duration of this study. His unwavering dedication to my research truly enabled me to conquer seemingly insurmountable obstacles. Second, I thank Dr. Nita L. Miller, thesis second reader, for her keen insights and caring touch that strengthened all aspects of not only this work, but my growth as a graduate student as well. Next, I would like to express my sincere gratitude to Dr. Kevin Bennett, Wright State University, for allowing me to use his interface design concepts in this study. Without his trust, confidence, and support, this research would not have been possible. Additionally, I would like to thank LTC David Hudak and the rest of the Army officers from TRAC Monterey, the NPS Operations Research program, and the NPS National Security program for rallying around me during an immense time of need to make sure I successfully completed this project. I owe a special debt of gratitude to Randy Green, Wright State University, for devoting several months of his time to write literally thousands of lines of computer code to ensure the interfaces and tactical scenarios used during this study operated without fail and ultimately produced the outcomes we had hoped to achieve. I would also like to convey my most heartfelt thanks and appreciation to my wonderful wife Alicia and our two amazing sons, Dylan and Adam. Their unconditional love, support, and encouragement throughout this entire experience gave me the strength and inspiration to persevere through difficult times and the toughest of challenges. I am truly blessed to have them in my life and by my side. I love you. Finally, I dedicate this thesis in loving memory of my Mother, who lived just long enough to see me achieve this major milestone in my life. I will always miss you.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Information is vital for success during war. According to Shapiro (1999), this truism dates back at least to the ancient Chinese writings of Sun Tzu. Accurate information on friendly and enemy activities reduces what Clausewitz called the "fog of war" and facilitates the rapid defeat of enemy forces on the battlefield. Since the turn of the twentieth century, information technology has continued to advance at an exponential rate, enabling commanders to take advantage of the speed, range, and lethality of modern weaponry. Bennett, Posey, and Shattuck (2008) suggest military applications continue to provide both the impetus for technological change and a testing ground for these applications.

Information technology advancements also make warfare more complex. Since the inception of the Force XXI modernization program, the United States Army has fielded numerous interfaces to leverage the capabilities of digital information systems (INFOSYS) during the command and control (C^2) of tactical operations. Many of these interfaces purport to enhance situational awareness (SA) by allowing the commander to access countless gigabytes of near real-time information. However, the sheer volume of information these sophisticated technologies provide often overwhelms the commander's ability to comprehend their meaning. This natural phenomenon of information overload degrades SA and increases the fog of war. As Hall (2000) asserts, many more years of development and experimentation are required before computers can meet all the conditions necessary to control modern forces on the battlefield. The goal of this thesis is to assist the U.S. Army in its efforts to develop and incorporate interfaces that provide effective support to military practitioners as they cope with the inherent complexities of C^2.

A. CHARACTERISTICS OF THE C^2 DOMAIN

According to *U.S. Army Field Manual (FM) 6.0* (2003), through command and control, the commander initiates the actions of, influences, and synchronizes the elements of combat power to impose his will on the situation and defeat the enemy. The critical role C^2 plays in success on the battlefield is not a new concept. From the ancient battlegrounds of Mesopotamia to the asymmetric combat zones of modern-day Afghanistan and Iraq, military commanders have practiced C^2 throughout the history of warfare. While the size and scope of military operations has transformed the theory of C^2 over the years, mission accomplishment has continued to remain its goal.

During tactical operations, C^2 is complex and dynamic. The fluid nature and harsh conditions of combat create friction, which makes performing even simple tasks extremely difficult (Kemmerer, 2008). Friction stems from multiple sources, but is routinely characterized by time-pressure, high personal stakes (risk), and uncertainty (Lipshitz, Klein, Orasanu, & Salas, 2001). Time-pressure occurs because events during tactical operations are extremely fast-paced. It is impossible to eliminate risk from combat operations since the loss of life is always a possibility. Uncertainty is inevitable due to the ways in which data are observed, measured, and reported. Further, the enemy is actively involved in deception and misdirection. The scope, complexity, and severity of the challenges within this domain of application are perhaps unprecedented (Bennett et al., 2008).

The complexity and uncertainty of modern warfare makes it impossible for commanders to effectively execute C^2 in isolation. Commanders require support from staff personnel to coordinate and synchronize finite resources such as people, equipment, technology, and logistics to achieve mission-related goals. Commanders also need help to determine the effects numerous interrelated factors (e.g., enemy forces, terrain, weather, time, etc.) will have on these resources as they execute tasks. At every echelon of command, each commander has a C^2 system to provide that support (Department of the Army, 2003).

According to *FM 6-0* (2003), the C^2 system strives to reduce uncertainty to manageable levels by enabling commanders to see themselves, the enemy, and the terrain. C^2 is part of the Battlefield Operating System (BOS), and integrates functions from the other six BOSs to accomplish the mission. The other BOSs include:

- Intelligence System
- Maneuver System

- Fire Support System
- Air Defense System
- Mobility/Counter-mobility/Survivability System
- Combat Service Support System

C^2 consists of two components: the commander and his C^2 system. Commanders use their C^2 systems to exercise C^2 over their forces to accomplish missions (Department of the Army, 2003). The commander, while having overall responsibility for C^2, must understand the situation before making decisions. Staff personnel assist the commander by collecting and processing data into relevant information (RI). Through RI, the commander gains understanding. The commander then uses his understanding to determine plausible courses of action (COA), and to issue timely directives.

Due to friction, uncertainty will always exist regardless of how well the C^2 system operates. Commanders and staffs must use information-focused and action-focused solutions to identify and reduce uncertainty (Department of the Army, 2003). Action-focused solutions consist of experience, training, and standard operating procedures (SOP). Information-focused solutions increasingly rely on computer-assisted information distribution, integration, and display processes. Thus, today's military practitioner requires an advanced C^2 interface that assists in seeing and understanding the entire battlefield.

B. THE RAPTOR INTERFACE

RAPTOR (Representation Aiding Portrayal of Tactical Operations Resources) is a prototype interface designed to be used in C^2 during tactical operations (see Figure 1). This study will examine if warfighter performance is enhanced by the cognitive systems engineering (CSE) approach and ecological interface design (EID) principles used to develop RAPTOR. The intent behind the CSE approach to RAPTOR's design is to provide the user with robust cognitive support to increase performance during C^2 efforts. Thus, the major goals for the design and implementation of RAPTOR are to facilitate better decision making and enhance operator SA by increasing understanding of the battlespace.

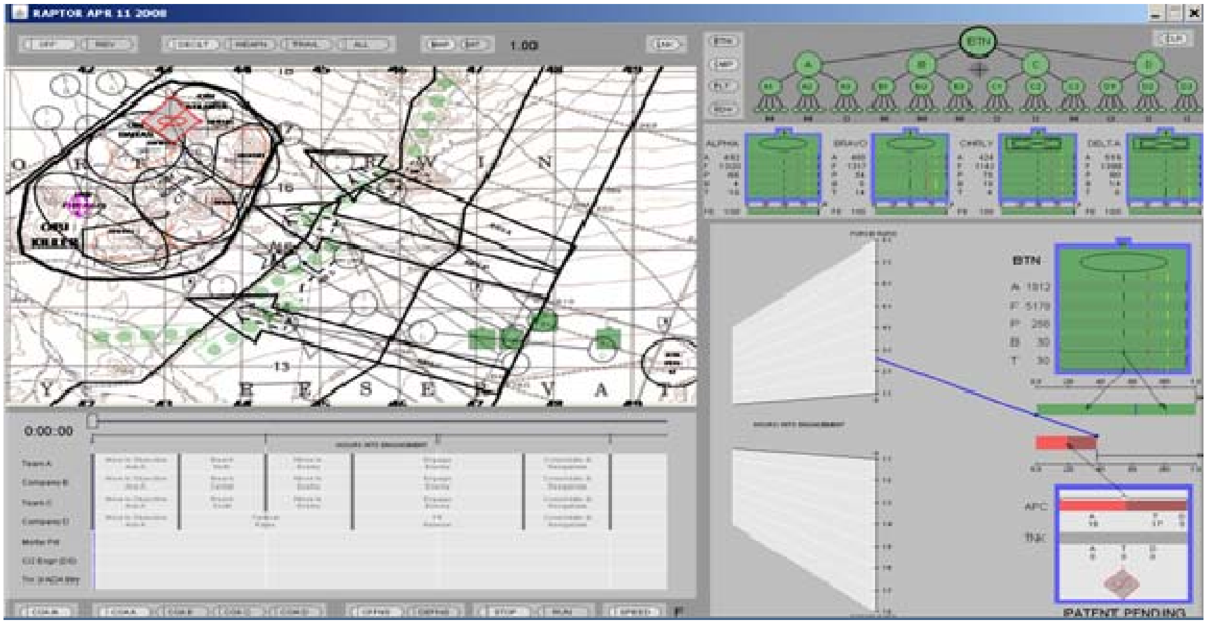


Figure 1. RAPTOR Interface (After: Bennett, Posey, & Shattuck, 2008).

Ultimately, the goal of interface design must be considered as the provision of effective decision and problem-solving support (Bennett et al., 2008). With this goal in mind, the extent to which an interface enhances operator SA and closes the “information gap” will determine the benefit of any interface to a tactical C^2 system (Endsley & Garland, 2000). Therefore, in the context of decision making, understanding, and SA, the degree to which the interface design improves human and machine interactions will determine total system performance. The more intuitive the system is to operate, the faster users can effectively incorporate the system into the work domain. Accordingly, the design principles and techniques used to develop RAPTOR will ultimately assist the U.S. Army in its efforts to incorporate advanced interfaces that account for human capabilities and limitations in the U.S. Army’s Battle Command System (ABCS).

A controlled laboratory experiment was the primary vehicle used to assess military decision makers’ performance while performing critical battlefield activities (e.g., gain and analyze critical knowledge on the effects of terrain; assess anticipated enemy actions on friendly force operations). Previous empirical examinations comparing RAPTOR to C^2 interfaces currently being utilized by the United States Army have already demonstrated RAPTOR’s potential to provide superior support to military practitioners as they execute C^2 activities. This study advances the development of RAPTOR by identifying areas for improvement in the interface design. This study also builds on work previously conducted, and further validates the ability of the interface to increase performance as users deal with uncertainty and novel situations in dynamic and fluid environments. Though the current version of RAPTOR was inspired by the complexities in C^2, the results of this study could potentially provide warfighters with a robust interface capable of assisting and supporting a variety of complicated tasks across a broad range of complex work domains.

In summary, the goal of this thesis was to demonstrate how effectively RAPTOR employed CSE and EID constructs to increase the military practitioner's understanding of the battlespace and to enhance SA. Though no interface will result in complete understanding or perfect SA, an interface designed to support the cognitive capabilities and limitations of the commander may lead to a significant tactical edge over threat forces (Libicki & Johnson, 1996).

C. HUMAN SYSTEMS INTEGRATION (HSI)

This study explores the effectiveness of RAPTOR in the C^2 system from the perspective of HSI. According to the principles of HSI, human considerations must be viewed as a priority in systems design to reduce life-cycle costs and improve total system performance (Miller & Shattuck, 2008). HSI strives to implement the human as the key element in the "system of systems" architecture by assisting in system designs that support human limitations and enhance human strengths. In order to accomplish this goal, HSI practitioners focus on inherent trade-offs within each of the following HSI domains:

- Human Factors Engineering
- Manpower
- Personnel
- Training
- Human Survivability
- Health Hazards

- System Safety
- Habitability

Considerations of human-centered design trade-offs early in the acquisition process promote system effectiveness, safety, and cost savings throughout the system life cycle (Miller & Shattuck, 2008). Further explanation of the domains, and the specific trade-offs within each domain, can be found in *Department of Defense Instruction 5000.2*, or *Handbook of Human Systems Integration* (Booher, 2003).

For the purpose of this study, exploration on RAPTOR's potential to assist and reinforce the military commander's ability to actively execute all aspects of C^2 will focus on the HSI domains of human factors engineering, training, and manpower. This study hopes to highlight the extent to which RAPTOR improves human performance, and to determine how well the interface and the human interact. Essentially, the level of achieved human-computer interaction will drive the time, cost, and types of training required for users to successfully operate the interface. The more intuitive RAPTOR is to operate, the faster users can effectively incorporate the interface into the C^2 system. The results could potentially reduce the manpower required to assist commanders at conducting C^2.

D. RESEARCH QUESTIONS

The role of sophisticated computer technology in the C^2 system raises several important questions. The following questions set this study's foundation, and also provide a basis for future studies aimed at designing interfaces capable of assisting and supporting a variety of complicated tasks across a broad range of complex work domains. When researching the problem from an HSI perspective, one must focus on symbiotic relationships that exist between the human and the machine.

- To what extent does sophisticated INFOSYS technology facilitate C^2? To what extent does sophisticated technology impede C^2?
- How do humans transform data into information? How do these processes enable military commanders to understand the battlespace?

- How do interfaces assist humans with the cognitive integration of information?
- How are perception and SA intertwined? How, at all, does SA affect decision making?
- How does an interface design affect the man and machine symbiosis?
- To what extent does RAPTOR increase warfighter performance during C^2 of tactical operations?

E. RESEARCH OBJECTIVES

The ultimate objective of this thesis is to facilitate interface designs that enhance total system performance. The specific objectives for the study are:

- Develop a methodology to assess how interfaces assist humans to achieve enhanced levels of SA and improved decision making.
- Develop tactical scenarios for modeling and simulation.
- Determine the extent to which warfighter performance is enhanced by RAPTOR's CSE and EID design approach.
- Emphasize the importance of HSI in exploring the role of sophisticated computer technologies in the C^2 system.
- Provide a clear direction for future studies aimed at incorporating advanced interfaces into the U.S. Army's C^2 system.

F. THESIS ORGANIZATION

A traditional format will guide the organization of this thesis. Chapter II provides a detailed examination of the CSE framework, and EID theoretical constructs used to guide RAPTOR's interface design. The process of transforming information into individual and shared understanding is further described. Also, the potential for interface designs to enhance military practitioner SA and decision-making are made explicit.

Chapter III focuses on the empirical evaluation of the RAPTOR interface. Detailed descriptions of the methodology (e.g., tactical scenarios, simulations, data collection techniques) used during experimental events are provided. Additionally, lessons learned during the experimental events are documented to assist researchers with future replications of the study.

Chapter IV reports the analysis of data collected during experimental events, while Chapter V discusses the implications of the data. Chapter VI provides conclusions and recommendations, and illustrates a “way ahead” for the development and evaluation of future interfaces designed for incorporation into complex work domains.

Appendixes are included to provide more detailed information about the experimental process. Appendix A and B provide copies of the tactical scenario operation orders that participants reviewed to prepare themselves for the experimental trials. Appendix C is the demographic survey used to compile participant professional data. Appendix D and E are the post-training tests used to ensure participants retained the comprehensive knowledge necessary to advance to the experimental trials. Appendix E is the feedback survey used to elicit specific comments from participants once they concluded all experimental trails. Appendix G illustrates the ad-hoc notes and tables Baseline interface participants created during the experimental trials.

II. LITERATURE REVIEW

A. C^2 DURING INFORMATION AGE WARFARE

1. The Role of Information Systems Technology in the C^2 System

According to *FM 6-0* (2003), the object of INFOSYS technology is to enhance the performance of people. Twentieth century warfare was fought primarily through platform-centric operations (PCO) (Department of Defense, 2001). Radios and telephones were the predominate means of communication between the commander and his subordinate leaders. Procedures for receiving and disseminating critical information proved extremely cumbersome, which often created confusion and hindered execution. As a result, commanders tended to make centralized decisions and commanded by plan, which ultimately depended on highly trained and disciplined Soldiers to carry out the plan as ordered (Phister, Busch, & Plonisch, 2003).

Operation Desert Storm exhibited the advantages information age technologies can provide to military commanders during combat. Lessons learned from the Iraqi Army's resounding defeat precipitated the U.S. Army's modernization process to "digitize" their entire INFOSYS structure. Since 1991, the evolution of INFOSYS technologies (e.g., satellite and digital communications) has ushered in network-centric operations (NCO) as a new theory of warfare (Department of Defense, 2001). NCO's concept is based on the use of technology to increase military effectiveness by enabling warfighters to rapidly share and utilize battlefield information during tactical operations. Simply put, realizing the full potential that advancements in computer, sensor, and communications technology can have on reducing the friction of war is sine qua non for NCO (Libicki & Johnson, 1996).

However, due to the speed and nonstop tempo of the modern battlefield, no C^2 system can work without INFOSYS capable of leveraging information-age technologies (Department of the Army, 2003). As a result, numerous automated command, control, communications, computer applications, and intelligence (C4I) interfaces have been incorporated into the ABCS. Essentially, ABCS integrates BOS INFOSYS to share near real-time information vertically and horizontally through strategic, operational, and tactical commands. Force XXI Battle Command, Brigade and Below (FBCB2) is the Army's primary C^2 interface integrated into the ABCS. FBCB2 displays graphical representations of tactical information, and can be used either on the move or in fixed command posts (CP). This robust network of integrated INFOSYS facilitates the commander's ability to act faster than the enemy, rather than just reacting to enemy actions.

Commanders and staffs who conduct C^2 from "digital" tactical operation centers (TOC) have the capability to receive, process, share, disseminate, and display information must faster than those who conduct C^2 from "analog" TOCs. Computers perform many lower order functions faster and more efficiently than humans. When used correctly, the speed and efficiency of computers enable commanders and staff personnel to spend their time and mental energy on higher level RI processes (i.e., information of importance to the commander and the unit), which leads to reduced uncertainty and better decisions. Conversely, when misused, computers can produce large quantities of irrelevant data that hamper the commander's ability to make timely and effective decisions.

People are the key components within any C^2 system. Even the most advanced technology cannot support the C^2 system without people (Department of the Army, 2003). Satellites and fiber optics can relay vast amounts of data across entire oceans and continents. Unmanned aerial (UAV) and ground vehicles (UGV) can stream countless hours of high-resolution video. Remote sensors, radar, and sonar can transmit multitudes of near simultaneous signals. However, interfaces designed on an incorrect understanding of cognition will ultimately degrade, rather than improve, performance (Klein, Ross, Moon, Klein, Hoffman, & Hollnagel, 2003). From an HSI perspective, the most important concepts concerning the impact of advanced INFOSYS technology on human performance in the C^2 system lie in the cognitive, information, and physical domains as described by Money (2001). For this study, the goal is to determine how effective RAPTOR's design is at supporting a decision maker's ability to separate fact from fiction during fluid situations.

2. Command on the Modern Battlefield

It is important to recognize that the speed and efficiency of INFOSYS technologies both increase, as well as degrade, the commander's ability to make decisions on the modern battlefield. NCO strives to ease the burdens of command by networking commanders, subordinate leaders, shooters, and battlefield sensors together through a robust, secure, and broadband "tactical Internet." For the first time in the history of warfare, warfighters possess the capability to share, analyze, collaborate, and internalize distant battlespace information in near real-time (Kemmerer, 2008). Commanders have the ability to digitally transmit (i.e., e-mail) graphical representations of their intent, concepts, and directives across the entire command. The end users (i.e., subordinate leaders, individual Soldiers, etc.) also have the ability to display, store, and retrieve information as needed. The increased speed, efficiency, flexibility, and reliability of modern communications enable commanders to decentralize decision making and leverage subordinate initiative to achieve mission-related goals.

In reality, many of the INFOSYS technologies that enable NCO have given little consideration to the role of the human in the design or implementation of the systems (Read, 2007). It is not surprising that the measures commonly used to determine INFOSYS effectiveness center around the processing power, storage capacity, and bandwidth provided by machines. These metrics are easily quantified and relatively simple to produce. On the other hand, determining human cognitive performance is extremely challenging due to the numerous variables and relationships involved. Accurate measurements of human cognition require a "constellation" of individual-difference indices that are time consuming to produce and difficult to quantify (Aldag & Power, 1986).

The failure to recognize humans as the critical information nodes within INFOSYS designs ultimately degrade total system performance and further complicate command. Tactical operations are ongoing on the modern battlefield. Commanders constantly receive influxes of new information that alter what was perceived as truth only moments before. Events proceed forward in time at a rate that can quickly outpace the commander's ability to comprehend their meaning (Phister et al., 2003). Though technology can be designed to provide countless terabytes of data at increasing speeds and efficiency, the warfighter's mental skills, judgment, and expertise will always be required to determine the data's relevancy.

3. Control on the Modern Battlefield

Success in command is impossible without control. When exercising control, the commander must understand the effects numerous interrelated factors (e.g., enemy forces, terrain, weather, time, etc.) will have on tactical operations as they make decisions and direct friendly forces toward mission accomplishment. NCO theory suggests that advanced INFOSYS technologies enable understanding by allowing commanders to access any type of data they desire in near real-time. However, as stated by Shattuck, Graham, Merlo, and Hah (2000), "technology often overwhelms commanders by providing them with more information than they can possibly use (p. 116)." Achieving understanding is primarily a human activity, and cannot be attained with technology alone.

As Figure 2 depicts, achieving understanding requires the transformation of information through four different levels of meaning called the cognitive hierarchy (Department of the Army, 2003). Data is at the lowest level of the hierarchy and comprises the unprocessed bits and bytes of information. Commanders and their staff collect, filter, and sort data to determine relevancy. Information is formed by relevant bits of data that are organized and fused together to provide meaning. Knowledge is inherently cognitive, and involves assigning greater values of meaning to information through further analysis and evaluation, until potential implications on tactical operations are recognized (Garstka & Alberts, 2004). Finally, understanding is achieved when the commander comprehends what is happening and why, and applies judgment to affect a specific situation's inner relationships (Department of the Army, 2003).

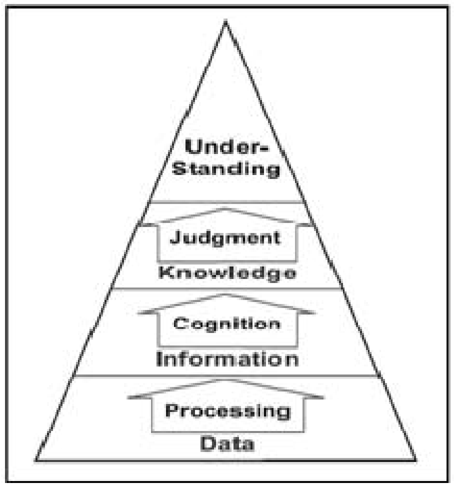


Figure 2. The Cognitive Hierarchy (From: Department of the Army, 2003).

In the context of the cognitive hierarchy, information management (IM) is an essential aspect of control. Staff personnel use IM processes to harvest and exhibit RI to facilitate the commander's decision-making process. Staff personnel assist with the control function by utilizing RI outputs (e.g., commander's intent, concepts, decisions, etc.) to build a common operating picture (COP). The COP serves as a guide for all echelons of command to follow while working toward a common goal. Interfaces play a crucial role in these control activities by enabling staff personnel to display the COP in efficient and usable formats. Commanders and staff personnel then leverage INFOSYS technologies and NCO networks to ensure the right information is shared with the right people at the right time (Garstka & Alberts, 2004).

B. UNDERSTANDING THE INFORMATION AGE BATTLEFIELD

1. The Cognitive Domain of Command

Understanding enables the commander to form a mental picture (i.e., battlefield visualization) of the friendly force's current state in relation to the enemy's current state both in time and space (Department of the Army, 2003). Forming this mental picture encompasses rigorous cognitive processes that allow commanders to:

- Make more accurate assessments for how the environment will impact operations (e.g., terrain, weather, temperature, light, time, etc.).

- Determine the current operational state of friendly and enemy forces (e.g., location, capabilities, status of resources, morale, etc.).
- Formulate alternative COAs that capitalize on friendly force strengths and enemy weaknesses.
- Direct forces in order to achieve mission related objectives (i.e., communicating intent, concepts, and decisions).

The proficiency at which decision makers apply these cognitive processes depends on the cognitive domain, or mind, of the individual commander. This is the part of a commander's brain where doctrine, TTPs, knowledge, SA, intent, and decision-making skills reside (Department of Defense, 2001).

Ultimately, INFOSYS' success in enhancing decision-maker performance relies on the integration of human cognition and technological capability (Read, 2007). The key to this integration is a firm understanding of the human cognitive capabilities and limitations within INFOSYS. A human's thought process, as described by Garstka and Alberts (2004), is a process of "sensemaking," or forming awareness of key elements relevant to the mission. The process begins when a person senses, or perceives, incoming stimuli (i.e., data). The person's cognition interprets meaning by forming schemas, or "mental models," to compare the information against similar situations experienced in the past. As the person makes sense of this mental picture, he evaluates available options, and then decides what action to take (Smith, 2006). Over time, people gain experiences from which they compile a repertoire of mental models that apply across a range of situations (Garstka & Alberts, 2004).

However, as previously discussed, humans have limited cognitive resources in which to comprehend large amounts of information. Constant influxes of ambiguous and/or conflicting information can severely impede a person's ability to make sense of the situation. Commanders may succumb to cognitive biases generated by their inaccurate interpretation of the environment (Garstka & Alberts, 2004). These biases potentially cause decision-makers to deviate from objectivity and make errors in judgment (Arden, 1996).

While certain cognitive activities (e.g., working memory) draw on limited-capacity resources, other activities (e.g., pattern-recognition) draw on virtually unlimited perceptual resources (Bennett, Payne, & Walters, 2005). Garstka and Alberts (2004) describe people's cognitive capabilities as very good at identifying patterns in disparate information, making inferences, and learning. Therefore, information complexity in itself is not a problem, given meaningful information is presented in a coherent and structured manner (Rasmussen, 1992). The essential notion being that in order for INFOSYS technologies to improve total system performance and effectiveness, information must be constructed into representations that exploit the inherent pattern-recognition capabilities of the human, while also decreasing reliance on limited-capacity resources (Bennett et al., 2005). Fortunately, as Rasmussen and Vicente (1990) argue, the power and flexibility of information technology make it possible for interfaces to adapt to human capabilities and limitations.

2. Cognitive Integration of Information

Shattuck et al., (2000) explains that "cognitive integration occurs as commanders and staffs extract data from disparate resources and combine them in ways to create a veridical, holistic view of the environment (p. 117)." Thus, the cognitive integration process aids the commander in achieving understanding. Commanders craft several products such as the commander's intent, commander's critical information requirements (CCIR), and planning guidance to describe their understanding (Department of the Army, 2003). Staffs, in turn, use these products to construct the COP.

The physical and information domains provide the infrastructural and informational foundation for information collection and integration (Garstka & Alberts, 2004). Money (2001) attributes the physical domain as the traditional domain of warfare. This is where the physical platforms and the communications networks that connect them reside. The information domain is where information is created, codified, and shared. This is also the domain where the C^2 of modern military forces is communicated, and where the commander's intent is conveyed (Department of Defense, 2001). The networks within the physical domain enable the transfer of information packaged in the information domain (Garstka & Alberts, 2004). As Figure 3 suggests, managing the cognitive, physical, and information domains while also analyzing and integrating information extracted from nodes located throughout the battlefield is an extremely dynamic activity.

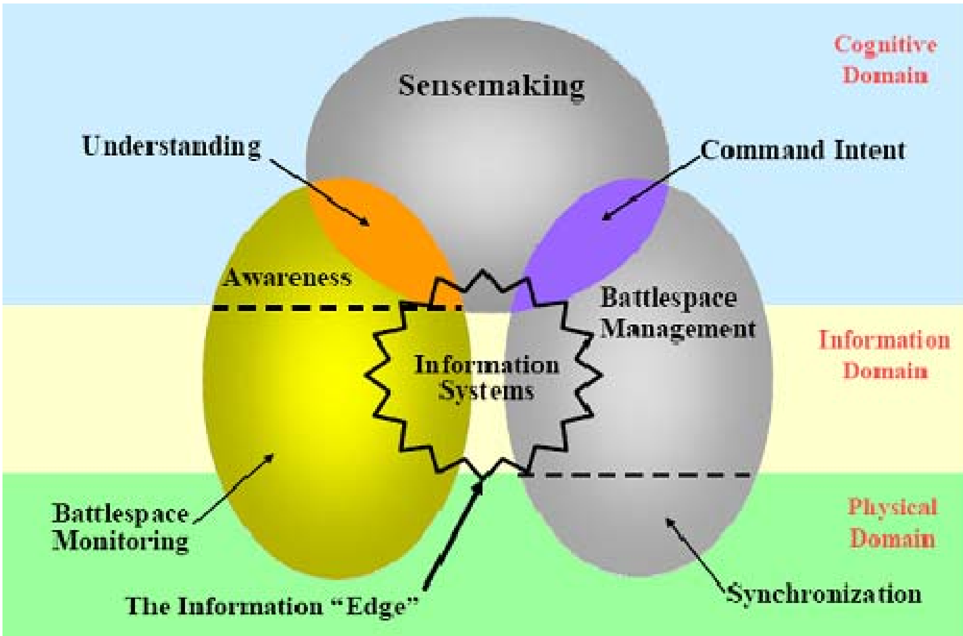


Figure 3. C^2 Conceptual Model (From: Phister, Busch, & Plonisch, 2003).

Thus, cognitive integration occurs in evolving contexts such as those inherent in the C^2 of tactical operations (Shattuck et al., 2000). For example, as tactical units execute assigned tasks in the physical domain, they report friendly and enemy actions in the information domain. The commander and his staff assess the causes for the action, and analyze the effects potential reactions will set in motion. Conclusions drawn from the analysis trigger more decisions to be made in the cognitive domain, which are subsequently disseminated in the information domain. This action-reaction sequence stimulates other agents to respond during ensuing cycles, with the cycles repeated time and again in the course of an interaction (Smith, 2006).

Integrating data collected from various technological sources and multiple agents is an arena in which C^2 interfaces can provide considerable assistance to commanders. For example, shifting at least some portion of the integration task to a cooperative machine agent frees the cognitive resources of decision-makers to reason about the situation in a more sophisticated manner. Second, interfaces designed to make salient the data that are most important focus the commander on the significant portions of the battlefield. Third, interfaces can enable commanders to employ simplifying strategies such as tracking events at higher levels of hierarchy that reduce their cognitive load (Shattuck et al., 2000). Also, in the context of on-going operations, interfaces can provide feedback loops that enable commanders to determine whether planned actions achieved or deviated from intended effects (Smith, 2006). Finally, interfaces can display the commander's battlefield visualization in meaningful and structured representations that subordinate leaders and Soldiers can understand and use when executing assigned tasks to achieve common goals.

C. THE CONGRUENCE OF DECISION MAKING AND SA IN C^2

1. Decision Making During Tactical Operations

FM 6-0 (2003) describes decision making as selecting the one most favorable COA to accomplish a mission. The United States Army's traditional view toward selecting the best COA is for commanders and staff personnel to use structured, analytical processes to generate and compare several alternative solutions to the problem until a superior solution is identified (Department of Defense, 2003). The Military Decision-Making Process (MDMP) is an example of an analytical or rational choice decision-making model routinely used at the tactical levels. MDMP's methodical process serves well for decision-making in complex and unfamiliar situations because it helps commanders and staffs organize their thoughts to ensure all factors have been considered, analyzed, and evaluated before reaching decisions. Though MDMP assists commanders in developing precise plans with minimal human error, its deliberate and time-consuming process is not appropriate during time-constrained situations commonly encountered during the execution phases of tactical operations (Department of Defense, 2003).

For the past couple of decades, numerous studies have been conducted to gain insight on how experienced practitioners make decisions in complex real-world settings characterized by time pressure, uncertainty, ill-defined goals, and high personal stakes.

Decision making in these types of environments are commonly referred to as naturalistic decision making (NDM), which has been widely accepted in recent years due to its utility in operational settings (Shattuck, 2007). The latest versions of United States Army doctrine recognizes NDM's utility during certain situations, and describes the process as intuitive decision making (Department of Defense, 2003). Perhaps most importantly, as stated by Kemmerer (2008), "NDM characteristics describe the situations and context for modern military exercises and engagements" (p. 9) (e.g., March 2002 combat operations to destroy al Qaeda and Taliban forces in Afghanistan's Shah-i-Kot Valley).

In examining the utility of NDM in tactical operations, Lipshitz, Klein, Orasanu, & Salas (2001) cite studies where naval surface ship commanders, tank platoon leaders, and infantry officers were used to determine decision strategies normally employed by proficient decision makers during complex and time constrained situations. Findings from these studies suggest that proficient decision-makers use their experience and training to pattern match appropriate responses to the given situation. They then develop and mentally wargame one plausible COA rather than taking time to deliberately and methodically contrast the COA with multiple alternatives using a common set of abstract evaluation dimensions (Ross, Klein, Thunholm, Schmitt, & Baxter, 2004). Therefore, NDM can be viewed as a form of satisficing, rather than optimization, since commanders often decide on COAs that are simply "good enough". Although a number of models fall within the NDM framework, Klein's Recognition Primed Decision-Making (RPD) model serves as the prototypical NDM model (Lipshitz et al., 2001).

The RPD model was developed on the basis that while under time pressure, commanders rely on past experiences to select their COA rather than generating a large set of options (Klein, 1993). The RPD model (see Figure 4) currently consists of three variations depending on the familiarity of the situation. During familiar situations, skilled decision makers can usually generate a feasible COA as the first one they consider. During settings where the situation is not clear, the decision maker will often rely on a story-building strategy to mentally simulate (i.e., wargame) events and construct one solution more plausible than another. In the third variation, the decision maker can employ a "progressive deepening" strategy to anticipate whether the COA will succeed or fail by determining if unacceptable consequences exist. If unacceptable consequences do potentially exist, the decision maker can continue to mentally wargame events until a reasonable alternative is identified (Lipshitz et al., 2001).

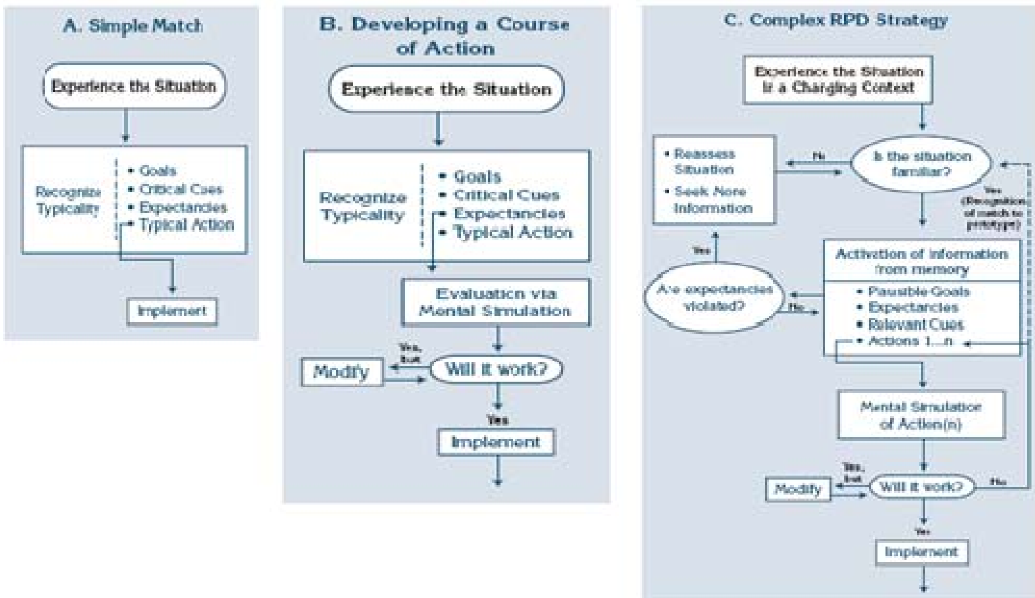


Figure 4. Recognition Primed Decision Model (From: Klein, 2008).

FM 6-0 (2003) stresses that analytical and intuitive decision-making are complementary thought processes. The use of one process over another depends on time available and the nature of the specific situation. Hamm (1988) even proposes that a proficient decision-maker's thinking will often shift between analysis and intuition, while never releasing his hold on either of the two. Nevertheless, most analytical models tend to ignore experience and perception as critical variables in decision making, while NDM models place them at the center of interest. The emphasis on perceptual processes and dynamic action constraints in decision making has increased the awareness of the potential role C^2 interfaces can play in providing effective decision support to commanders (Bennett et al., 2008). However, while the aforementioned models describe general processes of decision making during tactical operations, they do not address the role perception plays at shaping a commander's perspective for how a given decision may potentially influence specific events.

2. The Function of Perception in Dynamic Environments

Perception is an active process of inference in which a person constructs reality from raw data collected by the senses (Arden, 1996). In the context of dynamic environments, the most important aspect of perception is the extent to which the process enables a commander to accurately forecast how current events will potentially impact future goals, objectives, and end states. The perception of elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future is commonly referred to as situational awareness (Endsley, 1995). In tactical situations, accurate SA facilitates flexible and agile forces that are capable of acting faster than the enemy (Bushey & Forsyth, 2006).

SA is a dynamic and multifaceted concept that has been associated with complex military systems since the term was first introduced by United States Air Force pilots during the Vietnam War. *FM 1-02* defines SA as knowledge and understanding of the current situation which promotes timely, relevant, and accurate assessments of friendly, enemy, and other operations within the battlespace. The situations of most concern to the warfighter's SA are those which can vary rapidly, and which the commander is responsible for managing through decisive action. To be of value, the awareness of a situation of concern must cover all relevant factors, be up-to-date, be expertly interpreted, and capture the real meaning and full implications of the situation (McGuinness, 2004). Endsley (1995) portrays a warfighter's situation valuation process through three distinct levels of SA:

- Level 1 – perception of elements in the environment
- Level 2 – comprehension of the current situation
- Level 3 – prediction of the future actions of data elements

Success at higher levels of SA depends on a person's knowledge of events during the lower levels of SA. For example, a commander may perceive a deviation in the planned action of a subordinate element, comprehend how the deviation may endanger task achievement to potential enemy counter-actions, understand when and where the future contact will take place, and finally, predict how serious the outcome may be. The diagnostic distinction between the three levels is important because breakdowns in a perceptual/cognitive operation will possess very different consequences for addressing each level (Wickens, 2008).

It is important to point out that accurate decision making does not rely solely on a commander's achieved level of SA. It is entirely possible for a commander to have excellent SA and still disseminate poor directives because he may lack the requisite knowledge to implement corrective procedures aimed at remedying the situation. Likewise, it is also possible for a commander with minimal SA to implement timely and accurate decisions because his experience and training may be sufficient enough to offset his degraded view of the situation (Adams, Tenney, & Pew, 1995). Hence, it is worth noting that a commander must still understand the task demands regardless of the level of SA he has achieved. Therefore, in the context of dynamic environments, perhaps the most important concept of SA may be the degree to which the process facilitates a commander's coordination of his own perception, decision making, and action loop (Flach, 1995).

Like any complex work domain that relies on technology to assist operators as they cope with novel situations, the United States Military strives to develop interfaces that enhance SA and increase operator performance. Though seemingly simplistic, the tools often provided to enhance SA are no longer simple; they are amazingly intricate and require operators to perform elaborate perceptual and cognitive tasks (Endsley & Garland, 2000). As such, acquiring and maintaining high levels of SA must be appreciated as an integral part of the operator's mental workload (Adams et al., 1995). An increase in workload can divert scarce cognitive resources from maintaining SA, while a well-designed usable display can both reduce workload and increase SA (Wickens, 2008). Thus, when evaluating the scale to which new technological design concepts actually improve (or degrade) operator SA, it is imperative to systematically evaluate them based on a measure of SA (Endsley, 1995).

The magnitude to which evolving technology affects the man-machine symbiosis must be highlighted as a primary concern due to increasing dependence humans place on the use of computers and other automated tools. When determining an interface's effectiveness at assisting the warfighter with gaining understanding, maintaining SA, and decision making processes, one must apply a model that includes both man and machine. The model that best portrays this necessary relationship is the Dynamic Model of Situated Cognition (DMSC).

3. Situated Cognition in Fluid Real-World Settings

The tenets of NCO presume that a robustly networked force will ultimately result in dramatically improved mission effectiveness facilitated by enhanced decision-making and increased levels of SA (Garstka & Alberts, 2004). A 2002 study conducted by Maritime Systems Action Group One (MAR AG-1) specifically examined the "exponential" increases in mission effectiveness claimed for NCO technologies. Results of the study led MAR AG-1 to conjecture that a change in the use of technology (rather than a change in technology itself) is required since the positive effects of technology on human behavior is difficult to validate in all but the most simplistic of circumstances (Hazen, Burton, Klingbeil, Sullivan, Fewell, Grivell, Philp, & Marland, 2003). Thus, the challenges associated with integrating technological systems adept at supporting a warfighter's decision-making and SA in fast-paced and dynamic environments continues to remain a central concern within the United States military.

DMSC represents this integration of man and machine in tactical operations, and illustrates how human decision-making processes are influenced by technological agents. DMSC achieves this by providing a model that couples NDM theory (see Chapter II.C.1.) with a conceptual model that, unlike RPD, includes technology to provide a more robust insight into total system performance (Shattuck & Miller, 2006). Simply stated, in addition to the characteristics of individuals, DMSC takes into account that the design of an interface can also affect SA and decision making by representing the environment more or less accurately (Endsley, 1995; Shattuck & Miller, 2006). Thus, before discussing how interface designs can help commanders cope with the speed, uncertainty, and ill-structured situations inherent on the modern battlefield, one must first understand the inextricable links that exist between the technological components and the human agents in the C^2 system (Shattuck & Miller, 2006).

DMSC (see Figure 5) employs a process tracing technique (i.e., uses multiple data collection methods throughout the man-machine system) to assess human-system performance (HSP). This assessment is conducted by mapping a decision-maker's cognition (i.e., perception, interpretation, understanding, etc.) as events within operational settings unfold (Shattuck & Miller, 2006).

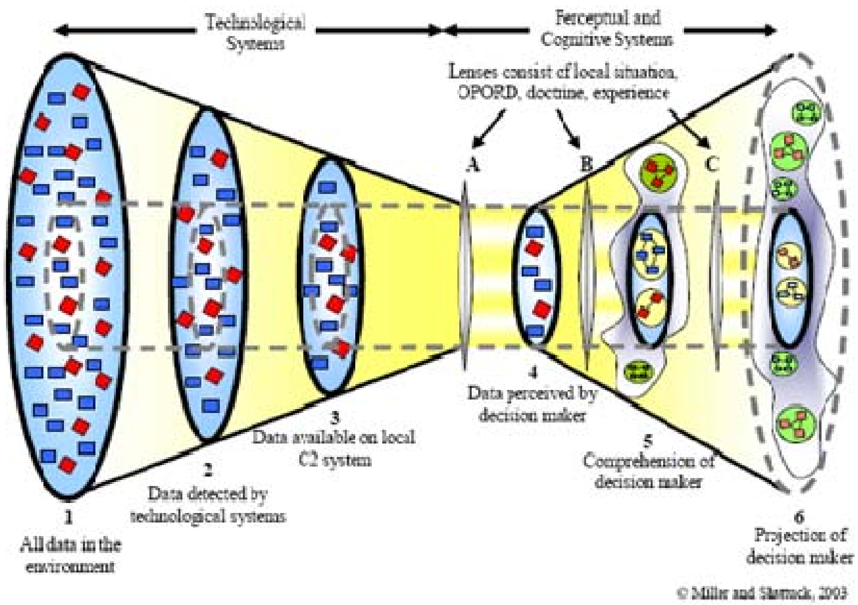


Figure 5. Dynamic Model of Situated Cognition (From: Miller & Shattuck, 2006).

a. Technological Aspects of DMSC

Oval 1 depicts everything in the environment. The various shapes and colors represent individual data elements located throughout the battlespace (i.e., terrain, weather, enemy, friendly, civilians, etc.). Oval 1 can be referred to as ground truth, or as a "God's eye view" of reality (Shattuck & Miller, 2006).

Oval 2 depicts those data elements accurately detected by battlefield sensors. Oval 2 contains only a subset of data from Oval 1 since it is impossible for even the most sophisticated array of technological systems to detect everything that exists within the environment.

Oval 3 represents data displayed on an operator's screen. Oval 3 is an even narrower subset of data due to the inaccuracies propagated by faulty sensors in

Oval 2. Misrepresentations can also occur when data is fused by flawed technological nodes linking Ovals 3 and 2 together, or can be misrepresented by poorly designed displays (Shattuck & Miller, 2006).

b. Human Aspects of DMSC

The model incorporates three lenses (labeled A, B, and C in Figure 4) that mediate how information is processed by the decision-maker (Read, 2007). As can be seen in Figure 6, the lenses focus attention toward certain data, and in some cases change, skew, and even bias how a commander perceives, comprehends, and makes projections as information passes through his individual lenses.

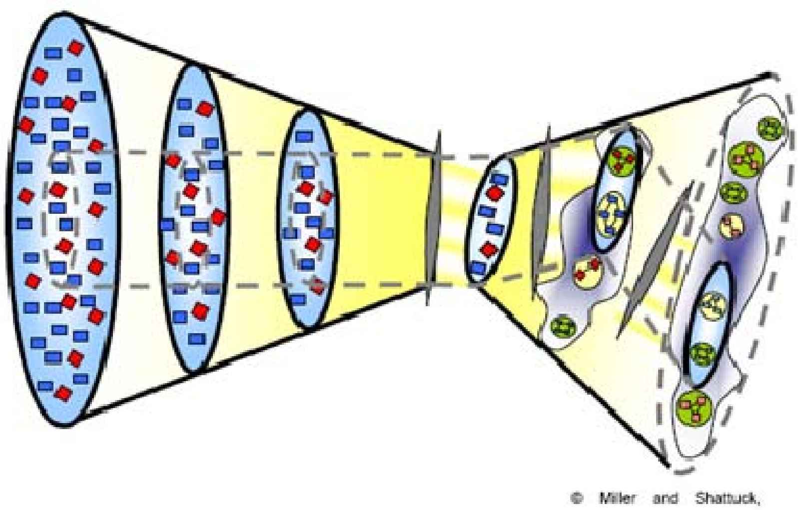


Figure 6. Integration of Distorted Information (From: Miller & Shattuck, 2006).

According to the model, Lens A directs the commander's attention to selected incoming stimuli (e.g., visual and auditory) from Oval 3. Oval 4 represents an even smaller subset of data perceived by the commander. Shattuck and Miller (2006) describe this perception process in terms of passive or active input. Active input can be considered as specific information requested by the commander, while passive input is non-requested information. Numerous factors (e.g., social culture, operational goals, guidelines, training, experience, and fatigue) contribute to the narrowing perception of data by influencing which stimuli a commander focuses his attention on.

Oval 5 represents comprehension (i.e., understanding) of the information, while Oval 6 represents the commander's projections (i.e., prediction). Lenses B and C are impacted by the same factors that directed the commander's attention and perception (Shattuck & Miller, 2006). By Oval 5, the commander will have made decisions and issued directives based on the way his cognitive processes fused, processed, and organized information filtered by Lens B. Oval 6 (Projection) is depicted by a larger broken border that illustrates the commander's mental model for what he believes to be true, and his projections for how future events will unfold. It is important to note that the amorphous shapes surrounding Ovals 5 and 6 represent varying interpretations of information (Shattuck & Miller, 2006). Though numerous commanders may receive the same data, their interpretations, decisions, and predictions may differ along varying degrees as their individual lenses influence their understanding and levels of SA.

c. Technological Influences on Decision-Making and SA

DMSC also incorporates feedback loops (see Figure 7) to provide insight into the cognitive processing and decision-making of a practitioner (Shattuck & Miller, 2006). SA and decision-making is an iterative process that evolves throughout a perception-action-reaction cycle, and is represented in Ovals 2 to 5. Understanding enables a commander to make projections for how he expects events to unfold. The commander may reorient battlefield sensors (e.g., UAV, UGV, etc.) to confirm or deny his expectations. This decision is represented by the feedback loop from Oval 6 to Oval 2. Additional data collected by sensors flow from Oval 2 to Ovals 3, 4, 5, and 6 (Shattuck & Miller, 2006).

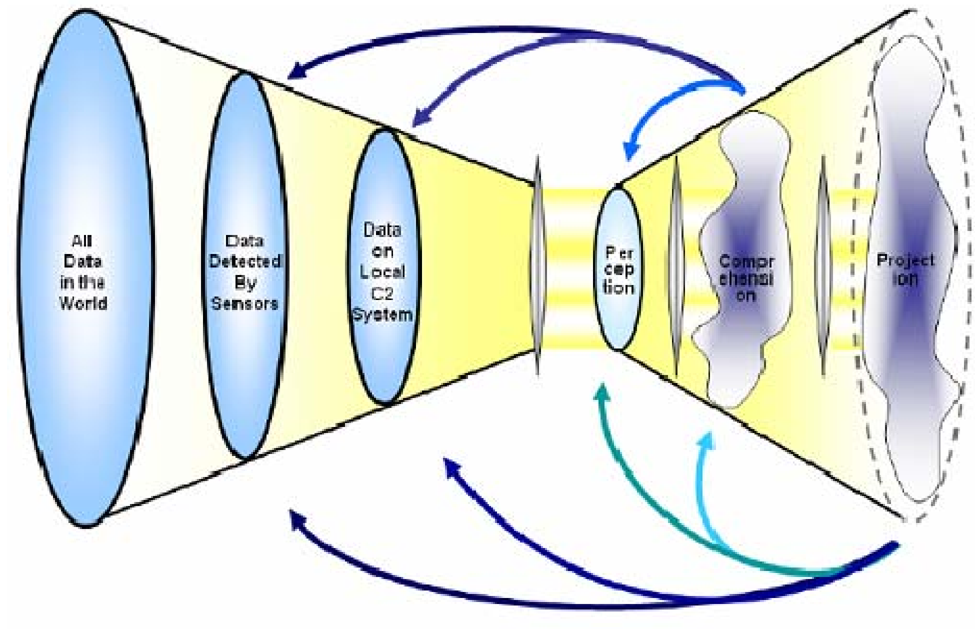


Figure 7. Feedback Loops in the DMSC (From: Miller & Shattuck, 2006).

These feedback loops highlight important considerations for C^2 interface designs. First, data must be presented (Oval 3) in a coherent and structured manner so that the operator can focus sufficient cognitive resources (Oval 4) to accurately interpret (Oval 5) meaning (Rasmussen, 1992). Next, perceptual cues provided by the interface display must be salient enough to assist an operator at determining how they expect events to unfold (Oval 6) (Bennett et al., 2005). Finally, information represented on the interface display must be sufficiently robust so that an operator can identify and mitigate uncertainty by refining sensor inputs, updating technological outputs, or changing their cognitive approach (Ovals 2 through 4) (Kemmerer, 2008).

These considerations, as well as the numerous other human system integration challenges described during the preceding discussions, set the conditions required to adequately portray how RAPTOR's design improves total system performance by supporting human capabilities and limitations.

D. THEORETICAL FOUNDATIONS OF RAPTOR

1. Cognitive Systems Engineering (CSE) Design Framework

The RAPTOR interface employs a CSE approach to assist military practitioners in executing C^2 during tactical operations. CSE provides the overarching framework, concepts, and analytical tools that can be used to guide the development of intuitive and highly graphical interfaces (Bennett et al., 2008). Unlike design schemes used for many expert tools, CSE emphasizes interface designs that support knowledgeable professionals by keeping, rather than replacing, the human in the loop (Potter, Elm, Roth, & Woods, 2001). Consequently, RAPTOR's design methodology seeks to capitalize on a military practitioner's experience, training, and knowledge by utilizing technology to transform decision-making from a cognitive activity to a perceptual activity (Bennett & Zimmerman, 2001). Therefore, the CSE process must be reviewed to appreciate how RAPTOR's design will enable military commanders to effectively see themselves, the terrain, and the enemy.

An effective CSE process must consider the three mutually interacting "behavioral-shaping" constraints of domain, agent, and interface in the design of a system (Bennett et al., 2008). These constraints have been discussed at great length throughout the preceding sections of this study, but can be summarized accordingly:

- **Domain** – goals, laws, physical, and functional considerations that lie within complex work domains.
- **Agent** – cognitive/perception/action capabilities and limitations of human agents conducting the specific work domain task requirements.
- **Interface** – functionality/design characteristics that introduce various resource demands on users.

As Figure 8 illustrates, the connections between these component constraints must be properly mapped in order for an interface to provide users with robust cognitive support as they execute multifarious tasks inherent in complex work domains (Potter et al., 2001). Thus, a fundamental premise of CSE is that a detailed analysis of the work to be accomplished within a domain of application is critical. Therefore, CSE provides analytical tools (the abstraction and aggregation hierarchies) to identify and thread fundamental component connections together during work domain analyses (Bennett & Zimmerman, 2001). Results of these analyses drive designs for the informational content that must be presented by interface displays.

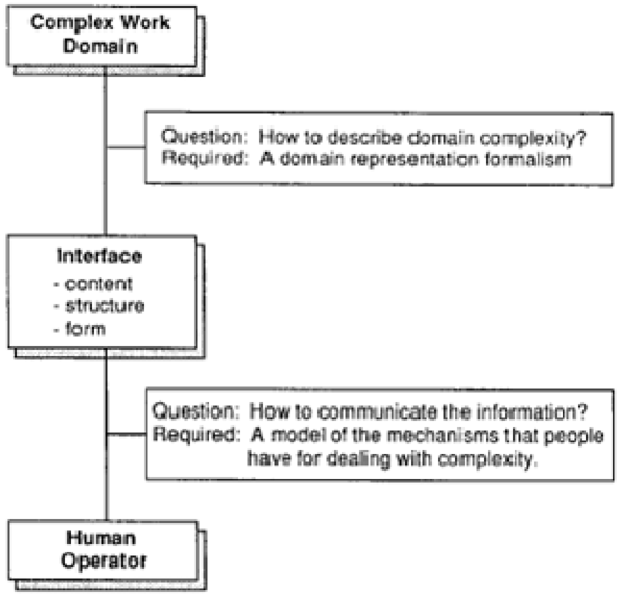


Figure 8. Structure of Interface Design Problem (From: Vicente & Rasmussen, 1992).

a. Abstraction Hierarchy

The abstraction hierarchy is a useful analytical tool for representing a work domain in a way that is relevant to interface designs (Vicente & Rasmussen, 1992). As previously discussed, in the C^2 system there are end-states (e.g., goals, objectives, etc.) that must be achieved, and finite resources (e.g., functional and physical means) that can be used to achieve those objectives. The abstraction hierarchy describes these "means-end" relationships that exist between goal and resource constraints along each level of the hierarchy. The general characteristics comprising each abstraction level in a C^2 system are:

- **Functional Purpose -** to synchronize combat resources and BOS elements to achieve mission accomplishment.

- **Abstract Function –** involves the appropriate allocation and expenditure of finite combat resources (e.g., people, equipment, technology, and logistics) to achieve objectives and goals.
- **Generalized Function –** comprises the numerous functions and activities performed by commanders and staff personnel during the C^2 of tactical operations. These tasks include gaining understanding, constructing the COP, making decisions, issuing directives, projecting future events, managing information, etc.
- **Physical Function –** requires an understanding of the capabilities and limitations of physical elements located in the environment (friendly and enemy). Examples include effective ranges of weapon systems, cruising speed of vehicles, sensitivity of sensors, payload capacity of aircraft, killing radius of munitions, physical fitness of Soldiers, bandwidth of INFOSYS, etc.
- **Physical Form –** requires an understanding for where physical elements are located throughout the battlespace (friendly and enemy). Also requires an understanding for the effects numerous interrelated factors (e.g., distances, terrain, weather, temperature, time, light, etc.) will have on these elements during tactical operations.

The resulting descriptions allow constraints to be mapped in terms of reasons, causes, and effects that are nested upwards and downwards through the abstraction hierarchy (Bennett et al., 2008). An important property of this mapping technique is that higher levels of the hierarchy require less detailed representations than lower levels of the hierarchy. As faults occur in the lower levels of the hierarchy, their causes and effects propagate upward through the hierarchy, while the reasons for the fault propagate back downwards to the lower levels of the hierarchy. The outputs of this mapping technique result in two important benefits: it provides operators with an informational basis for coping with unanticipated events, and provides a psychologically valid representation for problem solving (Vicente & Rasmussen, 1992).

Consequently, the abstraction hierarchy provides a design technique that allows RAPTOR to capture critical data pertaining to the goals, purposes and constraints of tactical operations, and then represents their information in the form of icons, graphs, charts, and tables directly on the display (Talcott, Bennett, Martinez, Shattuck, & Stansifer, 2007). As Figure 9 illustrates, these representations are arrayed either on, or along a contour map of the battlespace, which aids the operator in interpreting their meaning in time and space. Information presented in this manner provides visual salience, which enables the commander to focus attention on the priority measures that have a significant impact on operations (e.g., combat power, resource status, weapon range envelopes, force ratios, distances, terrain, time, etc.). Also, certain symbols are designed to change colors as events evolve (e.g., combat resource icons, combat resource displays, control tree, etc.). These changing colors represent either planned expenditures over time, or faults propagating upward through the hierarchy. Therefore, not only does RAPTOR's design help to make salient the data that are most important, but also provide the commander with feedback loops that assist him in determining whether actions achieved or deviated from intended effects. In short, RAPTOR's representations of critical cues in time and space can help a commander to cope with complex, dynamic, and novel situations by simplifying his overall sense of real-world problems (Smith, 1989).

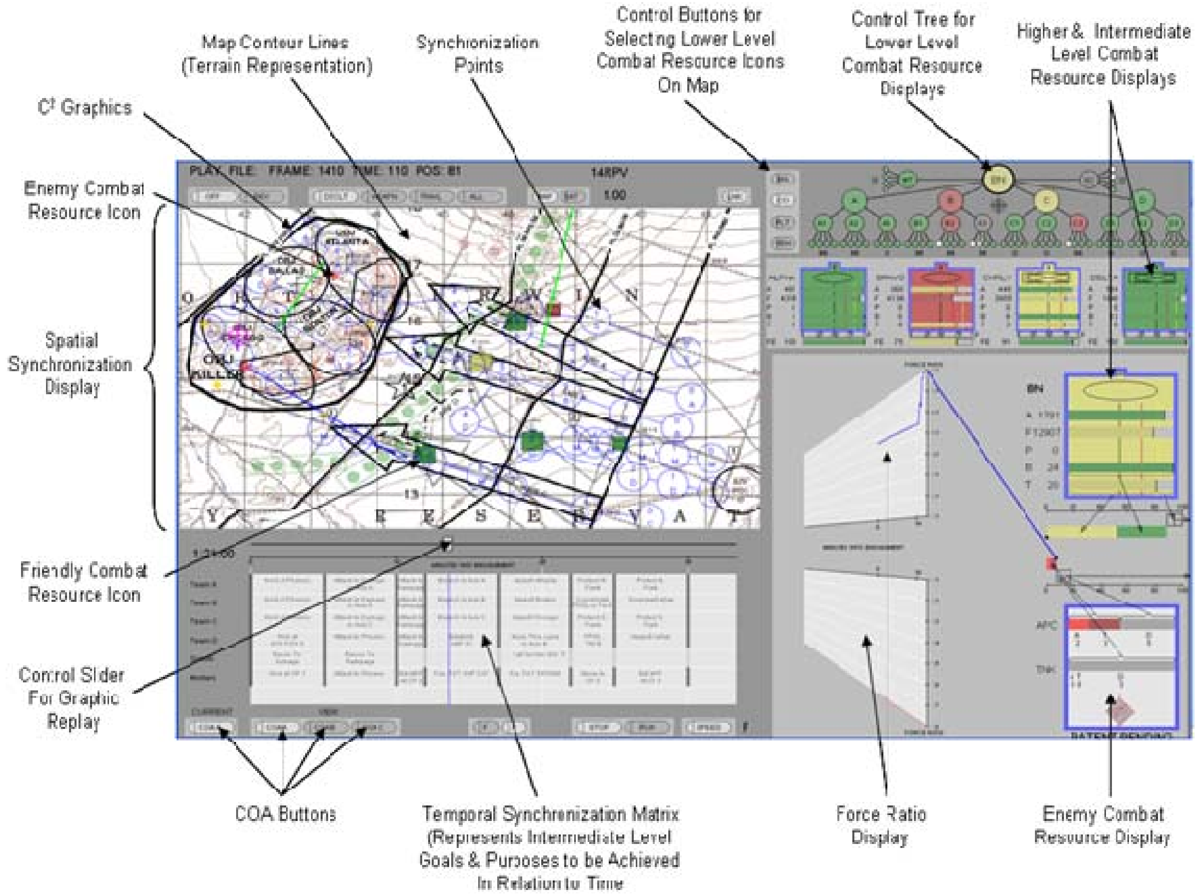


Figure 9. Overview of RAPTOR Interface.

b. Aggregation Hierarchy

The aggregation hierarchy is an analytical tool used to provide models for the "part-whole" structure of a domain (Bennett et al., 2008). As stated previously, the commander is overall responsible for C^2 and must understand the situation before making decisions. However, C^2's complexity makes it impossible for a commander to view, or even consider, the system's entire range of subcomponents and functions simultaneously. Fortunately, the aggregation hierarchy provides a mechanism for coping with this complexity by, as Vicente and Rasmussen (1992) succinctly describe, allowing the commander to "see the forest through the trees (p. 593)."

An important premise of the aggregation hierarchy is that higher level (i.e., less detailed) forms of representation are easier to comprehend and more efficient to manage than lower level (i.e., more detailed) representations (Vicente & Rasmussen, 1992). A simple analogy for this premise can be found in automobile warning lights. For example, a driver notices that a fault has occurred when the "check gauges" light illuminates on his dashboard. A quick examination of the gauges reveals the faulty function stemming from high engine temperatures. The driver stops his vehicle and continues his investigation by inspecting only those components that are functionally responsible for cooling the engine during operation. This is an efficient search since all components and subcomponents not related to the engine cooling system can be ignored.

Accordingly, RAPTOR's display presents icons, graphs, charts, and tables at higher and intermediate levels of visual salience. Information presented in higher levels of hierarchy reduces a commander's cognitive load by allowing him to employ simplifying strategies while monitoring battlefield events. The intermediate level representations cue the commander's attention toward faults that potentially jeopardize goals and objectives. Lower levels of detailed data are also updated, but these data are only available when "drilled-down," or accessed, by the operator. This design characteristic automates a portion of the information integration tasks, which frees additional cognitive resources that enable the commander to reason about situations in a more sophisticated manner (Talcott et al., 2007). Furthermore, RAPTOR's display design arranges the various forms of information in a vertical and horizontal array on a single screen. This arrangement supports the perception of information in time and space, and reduces the operator's workload by decreasing the need to divide attention between multiple sets of tools. Hence, decomposed representations of the C^2 system, displayed in a coherent and structured manner, ultimately enables commanders to problem solve in the same economic and proficient fashion as our fictional driver.

c. Skills, Rules, Knowledge (SRK) Taxonomy

While the abstraction and aggregation hierarchies provide models for mapping work domain constraints to interface designs, the SRK taxonomy provides a guide for communicating the domain design structure and information content to users. As previously discussed in Chapter II.B.1., operators must cope with the demands of the domain by utilizing their limited cognitive resources. Therefore, it is imperative that an interface design strategy takes advantage of the most powerful resources that people have for dealing with complexity. The SRK taxonomy provides a useful framework for capturing the various mechanisms people possess for information processing (Vicente & Rasmussen, 1992).

Skilled decision makers tend to use their experience and training to determine the relevancy for events transpiring during fluid and time-constrained situations (Lipshitz et al., 2001). Though Hamm (1988) agrees that perception is closely related to good performance, findings from his studies suggest that the skilled decision maker often shifts between intuitive and analytical modes of thinking when engaged in problem-solving activities (see Chapter II.C.1.). Therefore, SRK's most important concept is that it emphasizes the incorporation of both modes of cognitive control into interface designs since perception is not always superior to analysis.

In simple terms, RAPTOR displays information in accordance with standard United States Army symbols and icons that represent "signals" existing in the environment (see Figure 9). These signals provide "affordances," or actions, the operator must execute (Bennett et al., 2008). As illustrated in Figure 9, signal representations are arrayed on a contour map of the battlespace, which further aids the operator in interpreting their meaning in time and space. This design feature takes advantage of the commander's skilled-based behavior by enabling him to monitor the status of battlefield events while exerting limited conscious control.

Other informational representations presented in the temporal and spatial synchronization displays provide a set of explicit rule-based actions to be followed during the execution of tactical operations (see Figure 9). Successful rule-based behavior requires the operator to recognize previously devised cues (e.g., maneuver toward a specific terrain feature), and a conscious choice regarding the appropriate behavior when executing actions at those cues (e.g., transition to a different maneuver formation) (Bennett et al., 2008). In short, commanders can use RAPTOR's perceptual signals, cues, and their experience to quickly determine how they expect events to unfold (Bennett et al., 2008).

Knowledge-based behaviors involve situations that have not been previously encountered or accounted for during prior planning sessions. These novel situations require the commander to use limited capacity resources as he devises alternate COAs and considers probabilities of success for each response. RAPTOR's symbolic representations of graphical information (e.g., topographical map, combat resource display, primary munitions envelopes, control tree display, etc.) eases this burden by providing normative externalized mental models of processes that can support the commander as he pattern matches and mentally simulates responses. Thus, RAPTOR's use of robust representations exploit the military practitioner's experience and training, while also aiding in his analysis and decision making (Potter et al., 2001).

2. Ecological Interface Design Principles

The CSE portions of this chapter discussed how RAPTOR accounts for and leverages behavioral-shaping constraints inherent in the work domain and the agent. EID is a branch of CSE that specifically addresses the behavioral-shaping constraints inherent in interface designs (Bennett et al., 2008).

It is critical to understand that interfaces designed on an incorrect understanding of cognition will ultimately degrade, rather than improve, performance (Klein et al., 2003). Thus, any interface designed to support humans as they execute tasks in complex work domains must reduce the amount of cognitive demands placed on the operator. EID aims to accomplish this by making interfaces transparent and highly intuitive to operate (Rasmussen & Vicente, 1990). The following sections illustrate how the EID principles of direct perception, direct manipulation, and the perception-action loop have been incorporated into RAPTOR's design to transform the interaction requirements associated with decision making and problem solving from cognitive activities to perceptual-motor activities (Bennett et al., 2008).

a. Direct Perception

Rasmussen and Vicente (1990) assert that "interface designs must take advantage of the human's remarkable perception and action capabilities (p. 101)." The direct perception of signals and cues decrease cognitive resources and mental effort required, which allows the operator to use visual perceptual skills to make sense of events occurring in the battlespace. Enabling direct perception of events represented by interface designs requires at least two sets of mappings (Talcott et al., 2007). Gibson, as quoted by Rasmussen (1992), said the first set (i.e., content mapping) requires “the designer to create a virtual ecology” by mapping the means-end relationships that exist between domain constraints “in such a way that the user can read the relevant affordances for actions (p. 99).” In other words, content mapping encodes information content from all levels of the abstraction hierarchy in the form of graphical representations. Essentially, these representations mimic signals and cues an observer would encounter while operating in the natural environment.

However, designers must also guard against creating graphical representations in such complexity that they confound the observer’s ability to comprehend their meaning. Therefore, the second set of mapping (i.e., form mapping) involves the relationship between the visual properties of the graphical representations and the perceptual capabilities and limitations of the observer (Talcott et al., 2007). Form mapping results in representations that present the part-whole structure of a domain, which allows the operator to employ simplifying strategies (e.g., chunking) as they make sense of the overall problem space. Therefore, interface designs must facilitate the observer’s ability to determine the appropriate control actions to be executed based on the types of signals and cues perceived. Designs that allow observers to choose between varying levels from which to view graphical representations make it easier to perceive these signals and cues. The following discussion explicitly illustrates how RAPTOR’s rich set of graphical representations incorporate content and form mapping design principles that leverage the human’s perception and action capabilities.

(1) Spatial Synchronization Display. As can be seen in Figure 9, the left side of RAPTOR’s display represents coarser (i.e., high) levels of detail, while the right side represents finer (i.e., intermediate) levels of detail (Bennett et al., 2008). Figure 10 illustrates higher level representations of physical elements (terrain, friendly forces, enemy forces, and synchronization points) arrayed on a topographical

map. These provide the commander with salient visual representations of signals existing in the environment, and cues for actions that must be executed. Visual changes in the display (e.g., icon color changes) indicate either predetermined combat resource expenditures, or faults propagating upward through the hierarchy (e.g., a unit is in danger of not meeting mission requirements). These design characteristics provide feedback loops from which the commander can see deviations as they occur. Feedback loops assist the commander with making decisions that help influence how he expects events to unfold.

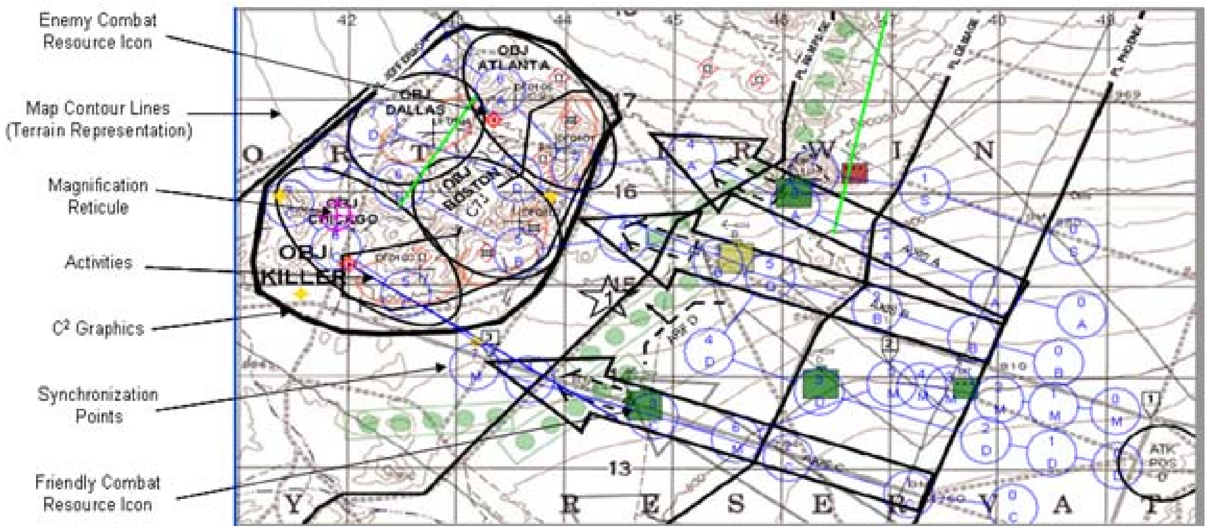


Figure 10. Spatial Synchronization Display.

(2) Temporal Synchronization Display. A critical aspect of control is the synchronization of combat force activities toward achieving common goals and end-states. Figure 11 depicts a representation of a combat activity coordinating tool (i.e., synchronization matrix) commonly used by commanders and staff personnel. The synchronization matrix meshes subordinate unit tasks with higher-level purposes. Though the spatial and temporal synchronization displays are being described separately, it is important to realize they are designed to work together in a complementary fashion (Bennett et al., 2008). Essentially, RAPTOR nests information in the temporal synchronization display with representations located in the spatial synchronization

display. This nesting technique provides the commander with visually salient depictions of critical activities to be coordinated in time and space.

As can be seen in Figure 11, the X axis of the display depicts time ranging from initiation of tactical operations to X + projected mission completion time. Present time for the engagement is depicted by the thin vertical blue line. The Y axis captures the identities of the maneuver elements represented as icons in the spatial synchronization display. The text located in the lighter cell areas specify tasks and purposes assigned to each maneuver unit. The thick gray vertical lines are tied to synchronization points presented in the spatial synchronization display (see Figure 10) and represent preplanned points in time, or conditions, where specific unit coordinating activities must be accomplished.

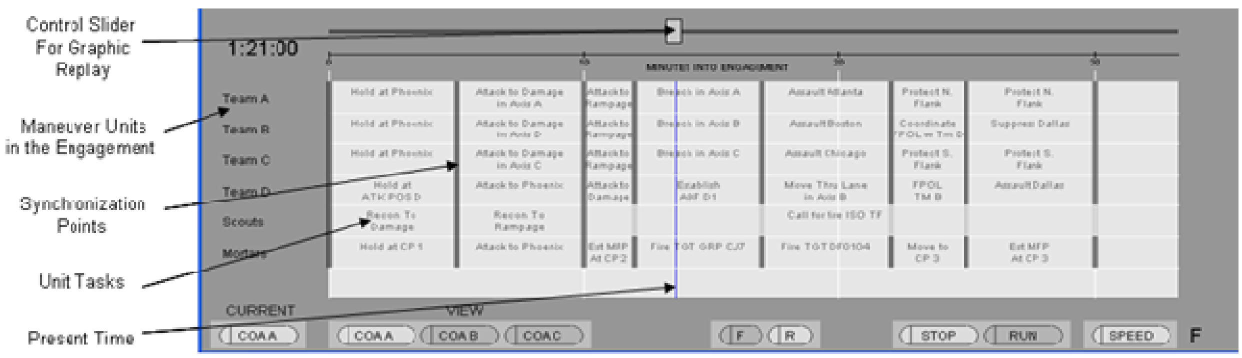


Figure 11. Temporal Synchronization Display.

(3) Friendly Combat Resource Display. Combat power is perhaps the most important factor a commander must consider when planning and executing tactical operations. The amount and type of resources that constitute overall levels of combat power will determine the feasibility of successfully achieving goals and objectives. As discussed in the opening chapter, combat resources are finite, and their expenditure must be proportional to any advantages gained during an engagement. Thus, the commander must constantly be aware of the levels at which these resources exist, and must understand how their expenditures will impact tactical operations.

Since overall mission accomplishment hinges on the ability of subordinate units to achieve individual assigned tasks, the commander must constantly know resource statuses for both the higher and intermediate organizational levels (i.e., battalion [BN] and company [CO]). During certain situations, the commander may also need to know lower-level resource statuses (i.e., platoon [PLT] and vehicle). Accordingly, RAPTOR provides salient representations of higher and intermediate combat resource levels. RAPTOR also provides the commander the ability to access lower combat resource levels when required.

RAPTOR displays combat resources using categorical, analog, and alphanumeric designators (see Figure 12). Alphabetical designators correspond to specific types of resources (A: ammunition, F: fuel, P: personnel, T: M1 Abrams tanks, B: Bradley Fighting Vehicles). Numeric designators correspond to quantities of a specific resource type on hand (e.g., F/12907 shown in Figure 12 depicts 12,907 gallons of fuel on hand). The color coding used to represent statuses are in accordance with U.S. Army conventions (green: 100% - 85%; amber: 84% - 70%; red: 69% - 50%; black: 49% and lower).

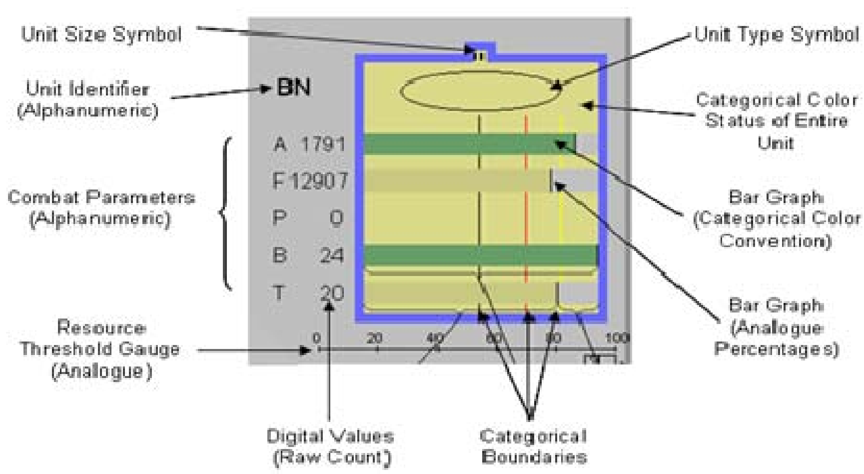


Figure 12. Friendly Combat Resource Display.

The bars in the resource display depict analog gauges corresponding to resource percentages on hand. These bars “shrink” as resources are expended. Bar color changes match percentage thresholds (e.g., bottom amber bar in Figure 12 depicts 84% - 70% tanks on hand).

Categorical conventions depict the overall color for the least resource percentage on hand. For example, if a BN's aggregate available resource percentages are 100% (Green) for vehicles, 100% (Green) for personnel, 84% (Amber) for ammunition, and 69% (Red) for fuel, the BN's categorical color convention would be red. The same categorical convention is also applied at the CO level. The background color for both the combat resource display, and its corresponding combat resource icon represented in the spatial synchronization display, reflect the categorical convention for the least resource percentage on hand (see "amber" status of "Charlie" CO in Figure 9).

Though resources may not be displayed in exact quantities, their representations are very salient, which enables the commander to "spot check" and loosely monitor the status of specific resource parameters at any level desired (Bennett et al., 2008). This design characteristic provides feedback loops from which the commander can anticipate potential deviations before they occur, and to make decisions that minimize deviation effects.

(4) Enemy Combat Resource Display. Commanders and staff personnel need information for similar types of combat resources and capabilities that the enemy possesses in order to anticipate the extent to which the enemy can impede tactical operations. In reality, determining precise types and quantities of enemy resources are rarely achieved. However, major enemy combat platforms and weapon systems can be approximated using established enemy doctrinal templates, inputs from battlefield sensors, and various forms of intelligence estimates. Commanders and staffs use these approximations to determine the appropriate allocation of friendly resources that will enable mission success. Just as the commander must monitor the status of friendly resources during the course of tactical operations, he must also monitor the status of enemy resources to make more accurate projections for how he anticipates battlefield events to unfold.

RAPTOR provides salient representations of known and suspected enemy resources to assist the commander as he makes decisions based on projected outcomes (see Figure 13). As enemy elements are positively identified, known (i.e., alive) enemy values increase, and suspected (i.e., templated) values decrease on the display. Consequently, as enemy elements are disabled, alive values decrease while disabled values increase.

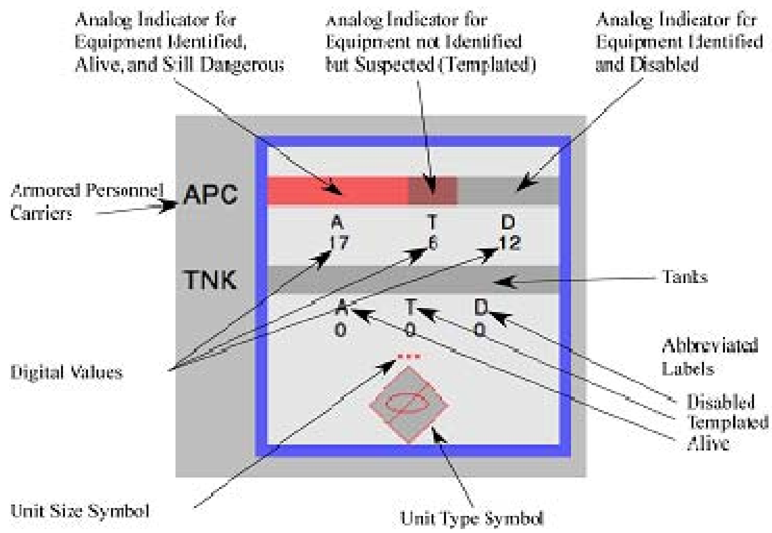


Figure 13. Enemy Resource Display (From: Bennett, Posey, & Shattuck, 2008).

Enemy combat resources are also tied to representations presented in the spatial synchronization display. Their specific composition and strength are represented using enemy symbols in accordance with U.S. Army conventions (see Figure 10). Salient visual representations of enemy combat resources assist the commander with determining how to employ friendly force capabilities based on the enemy's strengths and weaknesses.

(5) Force Ratio Display. Another extremely important consideration in tactical operations is the relative amount of combat power that exists between two opposing forces at any point in time (Bennett et al., 2008). Commanders and staff personnel analyze the enemy's composition (e.g., tank and infantry fighting vehicle quantities) when determining appropriate allocations of friendly combat resources that will enable mission success. For example, U.S. Army doctrine specifies a force ratio of at least three to one when attacking enemy defensive positions.

Predetermined estimates for how force ratios are anticipated to evolve must be continuously monitored during an engagement to assess progress toward achieving mission goals and objectives. A lack of progress depicted by force ratio changes in favor of the enemy will drive a commander's decision on whether to continue, alter, or abort mission plans (Bennett et al., 2008).

RAPTOR provides a display that presents the commander with salient visual representations of force ratio (see Figure 14). Two trend displays are depicted on the left side of the larger force ratio display. The Y axis of the top trend display represents planned and actual values of friendly force ratios, while the Y axis of the bottom trend display depicts actual and planned values of enemy force ratios. The X axis of both trend displays depicts time ranging from the engagement's initiation to X + projected mission completion time.

Two horizontal bar graphs are depicted on the right side of the larger force ratio display. The top horizontal bar graph is segmented between friendly tanks and Bradley Fighting Vehicles. The bottom horizontal bar graph is also segmented between alive and templated enemy combat platforms. The horizontal extent of each bar graph toward the right represents the force equivalence values for friendly and enemy forces (Bennett et al., 2008).

The two horizontal bar graphs are connected by a thick blue line (i.e., reflecting line) that provides a visual indicator for the difference between friendly and enemy force equivalence. The reflecting line also intersects the force ratio values depicted by the trend displays. The line expands horizontally across these displays as time progresses. Favorable friendly force ratios are represented by a blue line intersecting through the top trend display. Favorable enemy force ratios are represented by a red line intersecting through the bottom trend display. Variations (or waves) in the reflecting line depict rates of force value changes over time. Dark color variations represent actual force ratios, while light color variations represent planned force ratios. As can be inferred, reflecting line intersection locations, colors, and vertical variation distances provide salient feedback loops for how the commander can expect events to unfold.

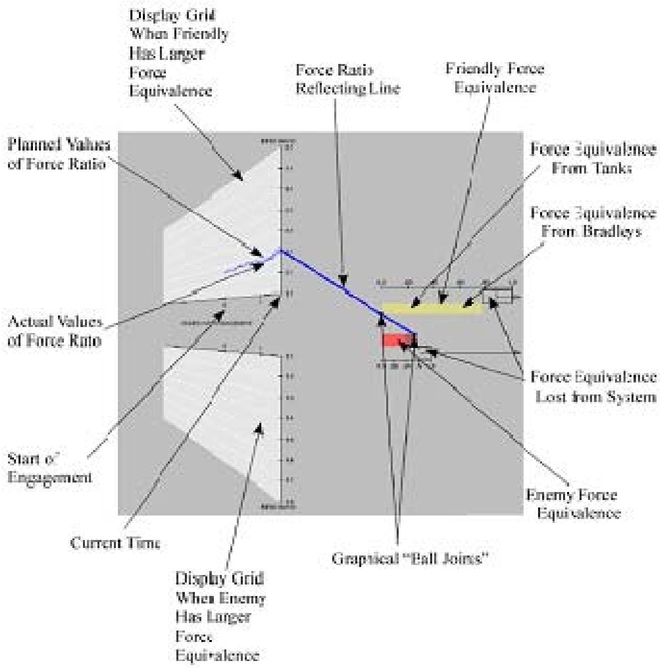


Figure 14. Force Ratio Display (From: Bennett, Posey, & Shattuck, 2008).

(6) Other Perception Enabling Tools. RAPTOR also provides additional tools designed to take advantage of human perception. For instance, the plan review mode is a tool that enables commanders to track how an engagement was originally planned to be executed, while also displaying how events actually progressed. A simple analogy taken from the analysis of a football play makes this premise concrete. As a television football commentator analyzes a specific play for the audience, he displays a visual depiction for how the play was designed to be executed (e.g., arrows, lines, Xs, and Os). He then overlaps a recording for how the play was actually executed so the audience can see where deviations occurred.

The plan review mode displays planned friendly locations, activities, and resources with icons containing a black "X" (actual icons do not contain an X) in the spatial synchronization display (see Figure 15). The plan review mode also displays and highlights preplanned categorical color codes on the right side of the analog bars located in the friendly combat resource display. The plan review mode enables the commander to determine exactly which deviations occurred in combat resource expenditures during precise points in time.

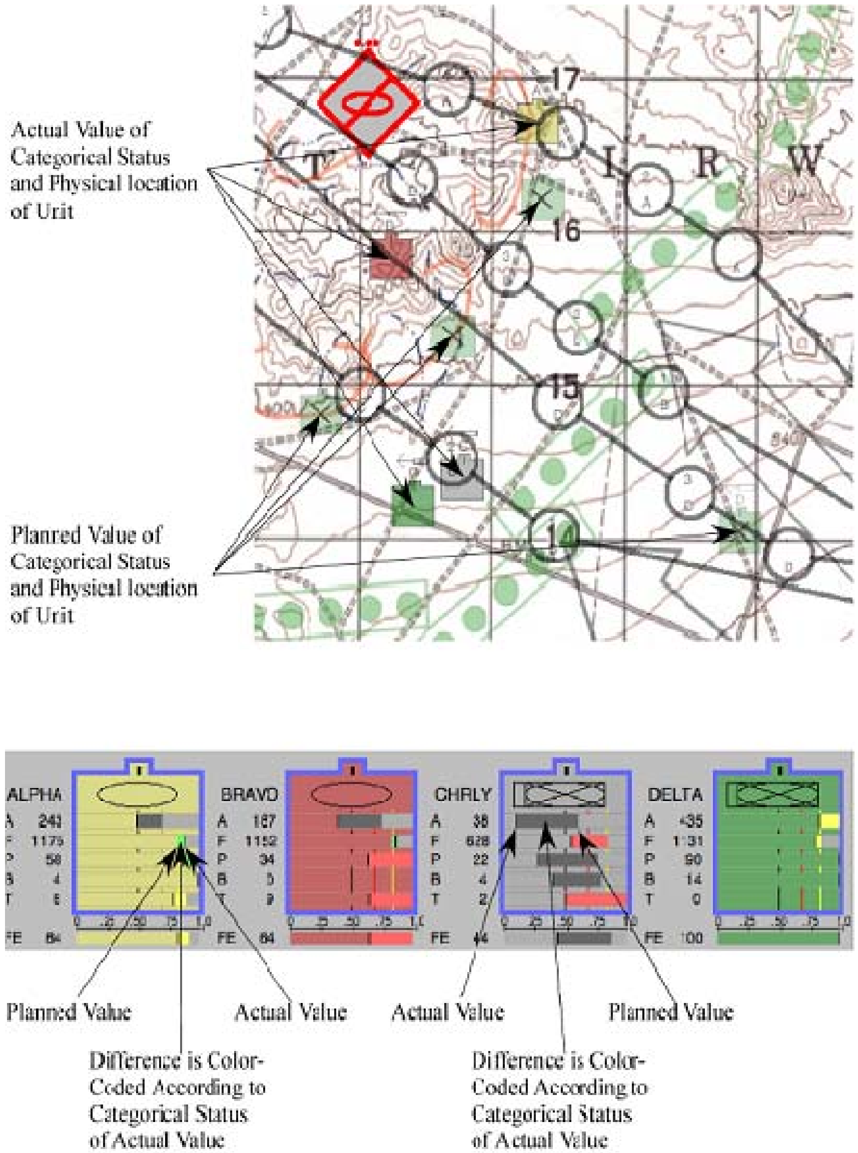


Figure 15. Plan Review Mode (From: Bennett, Posey, & Shattuck, 2008).

Another tool provided by RAPTOR is the depiction of pre-planned, alternative COAs. Commanders and staff personnel routinely develop multiple COAs that address different actions subordinate units can execute based on likely, or anticipated, deviations in the plan. These COAs can be thought of as "primed plays" the commander can "audible" should conditions dictate their implementation. The commander can review preplanned, alternative COAs at any time by rolling the cursor over labeled buttons at the bottom of the display (see Figure 9). Representations of the alternative COAs will temporarily replace current COA representations in the spatial and temporal synchronization displays. As likely deviations in the current COA emerge, the commander can choose to implement a preplanned, alternative COA by clicking on the corresponding button, then verifying the change. This audible constitutes a major modification to the existing plan, which can be viewed by other friendly elements monitoring networked RAPTOR interfaces.

b. Direct Manipulation

For an interface to be truly effective at taking advantage of human perceptual capabilities and limitations, the displays and controls of the interface must be designed to maintain an intact perception-action loop (Talcott et al., 2007). Direct manipulation is a critical enabler for maintaining this loop since it allows operators to feel like they have control over objects located in the environment. An analogy using vehicle operation provides a concrete example for how direct manipulation is tied to the perception-action loop. As a driver operates a vehicle in the environment, he perceives various signals (e.g., the road, other vehicles, pedestrians, etc.) that prompt actions to be executed. As the driver executes actions (e.g., manipulating the steering wheel, accelerator, and brakes), he receives immediate feedback (e.g., feels vehicular responses) for how well the executed actions enable continued vehicular control. Thus, the fundamental goal in achieving direct manipulation is to allow domain practitioner's to execute required command inputs by acting directly on representations in the interface (Bennett et al., 2008).

EID principles extend the benefits of direct manipulation to interfaces located in complex work domains (Vicente & Rasmussen, 1992). The objects in the interface can be designed to support both perception (direct perception) and action (direct manipulation). When this symbiotic relationship exists in an interface, the perception-action loop is intact. RAPTOR embraces direct manipulation to the fullest extent (Bennett et al., 2008). Unlike FBCB2, RAPTOR does not use command lines and pull-down menus. RAPTOR's design allows users to directly act on what they see in the display by physically manipulating the objects on their screen (Vicente & Rasmussen, 1992). Thus, all potential actions by the commander are executed directly on the interface. The merger of displays and controls on the RAPTOR interface ensures an intact perception-action loop, thereby enhancing the commander's perception of events and actions occurring in the battlespace (Bennett et al., 2008). The following sections describe how RAPTOR's design enables operators to directly manipulate representations located in the interface.

(1) Synchronization Points. Synchronization point representations in the spatial and temporal synchronization displays can be directly manipulated to assist the commander with controlling friendly force activities during tactical operations (see Figures 10 and 11). For example, the commander can point, click, drag, and release synchronization points represented in the spatial synchronization display to change destinations where a unit maneuvers toward. Similarly, the commander can also adjust activity timing by dragging vertical synchronization points represented in the temporal synchronization display. Dragging synchronization point lines left advances coordination timing, while dragging lines right delays coordination timing. These manipulations constitute minor adjustments in the plan, and in essence, communicate a command directive. Units affected by the change are able to view the modifications as they monitor their networked interfaces.

(2) Graphical Replay Slider. RAPTOR provides commanders with the ability to review historical events and preview planned events. The graphical replay slider is located at the top of the temporal synchronization display (see Figure 9). The graphical replay track (i.e., horizontal line) represents execution time ranging from the initiation of an engagement (i.e., extreme left limit) to X + projected mission completion time (i.e., extreme right limit). The physical location of the manipulable slider (i.e., square button) along the track corresponds to current time.

The commander can "rewind" through historical events by dragging the manipulable slider left. He can then view a "replay" of the engagement by dragging the slider to the right. The replay continues until the commander drags the manipulable slider right of current time, which then changes the display to a preview of preplanned actions. Current mission information remains displayed as the commander reviews and previews events. The manipulable slider springs back to current time when released.

Thus, the graphical replay slider enables the commander to see exactly which deviations occurred during specific points in time. The slider also enables the commander to anticipate potential future deviations as he previews planned activities. This design feature provides feedback loops that assist the commander in determining the extent to which preplanned actions will enable projected events to unfold as expected.

(3) Other Manipulable Tools. As stated earlier, higher levels of representation enable operators to better cope with complex and novel situations. However, effective interface designs support both intuitive and analytical modes of thinking by enabling the operator to choose which level of aggregation to view information from. Accordingly, RAPTOR provides several options that allow the operator to access and track several levels of information in an efficient and economical fashion.

The tree control and button controls located on the top right-hand side of the interface provide options for selecting various levels of combat resource displays (see Figure 16). The tree control is similar to task-organization charts commonly used by commanders and staff personnel, and depicts the overall unit structure down to the CO, PLT, and vehicle levels. The tree control provides a mechanism for the commander to view combat resources at any level desired. The default setting depicts combat resource displays at higher (BN) and intermediate (CO) levels (see Figure 9). The “bubble” color codes represent categorical combat resource statuses.

The commander can temporarily change the viewable level by rolling the cursor over any element depicted in the tree control. For example, rolling the cursor over A CO will highlight the “A” bubble, and will change the higher-level combat resource display to A CO. This will also change the intermediate-level resource display to the three PLTs assigned to A CO. Similarly, the commander can continue to access combat resource information down to the vehicle and individual crew levels by rolling the cursor over a PLT (e.g., A1) or individual vehicle bubble. Conversely, the commander can select a permanent view by pointing and clicking on a desired bubble. The combat resource display changes back to the default settings once the commander either removes the cursor from the lower level bubbles, or clicks the BN bubble.

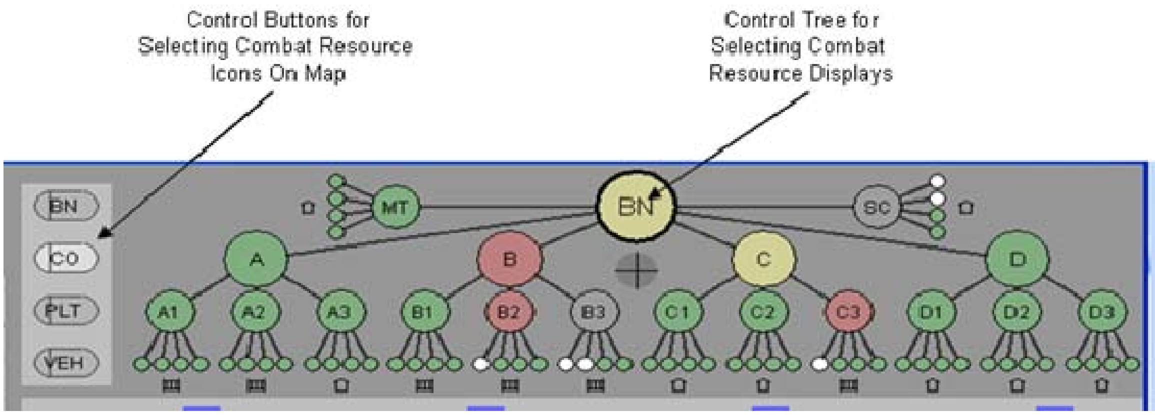


Figure 16. Tree Control & Button Controls.

The control buttons located on the left side of the tree control (see Figure 16) enable the commander to view physical locations of higher-, intermediate-, and lower-level combat resource icons located in the spatial synchronization display (see Figure 9). RAPTOR's default setting represents combat resource icons at the CO level. As stated previously, the icon color codes correspond to categorical combat resource statuses. The commander can choose to temporarily view all combat resource icons at higher (i.e., BN) or lower levels (i.e., PLT and vehicle) by rolling the cursor over the BN, PLT, or vehicle control buttons. Conversely, the commander can select a permanent icon level by pointing and clicking on a desired button. The default setting is reestablished once the commander either removes the cursor from a button, or clicks the CO button.

Viewing the entire range of combat resource icons at lower levels clutters the spatial synchronization display and provides potentially overwhelming amounts of information. Therefore, RAPTOR's design enables the commander to access any combination of lower-level unit information in an easy and efficient manner. For example, the commander can display a company's lower-level resource icons by pointing and clicking on a specific CO icon in the spatial synchronization display. This results in the replacement of that CO icon with its three PLT icons. The other CO icons remain unchanged. Similarly, vehicle level icons can be displayed by clicking a PLT icon. This design feature enables a commander to successively drill down to desired levels and views. Default settings are reestablished by clicking the CO button located in the button controls (see Figure 16).

Finally, the commander can also "magnify" portions of the topographical map presented in the spatial synchronization display. As previously discussed (see Chapter I.A.), terrain posses several constraints that potentially impede progress during tactical operations. Thus, the commander must determine the effects terrain will have on friendly resources as they execute tasks. Screen resolution settings, and multiple representations arrayed on the map often masks terrain contour lines. The commander can investigate finer terrain details by pointing on the purple-colored reticule, and turning the mouse wheel clockwise (see Figure 10). Selected portions of the map will magnify to higher resolution levels. Turning the wheel counterclockwise restores the selected portion to the default resolution settings.

E. PREVIOUS RAPTOR STUDIES AND EVALUATIONS

RAPTOR has already demonstrated its potential at improving the military practitioner's performance while executing C^2 of tactical scenarios. During a study in 2007, active duty U.S. Army officers were required to perform well-constrained, but critical tasks of obtaining friendly force combat resource information (e.g., fuel and ammunition) at three different echelon levels (Talcott et al., 2007). Participants performed the study in a controlled laboratory setting using simulations of both the FBCB2 and RAPTOR interfaces. The results of the study showed that RAPTOR was superior to FBCB2 in all assessment categories (quantitative, categorical, and needs), dependent variables (accuracy, latency), and echelon levels (BN, CO, PLT). The conclusion of the study determined that perception-icon design strategy was very effective in that experimental context. Actual or potential applications from the study included both specific interface design strategies for military C^2 and general interface design principles for intermediate work domains (Talcott et al., 2007).

Another study was conducted to investigate aspects of decision making (Bennett et al., 2008). Two versions of RAPTOR (i.e., enhanced and baseline) were developed for the study. Active duty U.S. Army officers assumed the role of BN commander and viewed dynamic, authentic tactical scenarios (either offensive or defensive) using one of the two interfaces. The participants were required to answer specific questions pertaining to the scenario at six different points that coincided with critical events. The results of the study showed that those participants who used the enhanced RAPTOR interface exhibited a greater tendency to produce references to plans and operations orders. Twice as many references to mission plans were made by those participants using the enhanced interface (52) than those using the baseline interface (26). Substantially more references to the mission operations order were also made by participants using the enhanced version (24 versus 15) (Bennett et al., 2008).

RAPTOR's initial successes illustrate the interface's potential to facilitate better decision-making and enhanced SA as military practitioners C^2 tactical operations. Thus, this study aims to further advance the development of RAPTOR by building on work previously conducted. This study will also aims to validate the interface's ability to increase total system performance as users deal with uncertainty and novel situations inherent in dynamic and fluid environments.

F. HYPOTHESES

The literature review has uncovered many important questions concerning the ability of interfaces to increase human performance during C^2. Though much of the concepts previously described yield multiple interesting topics that could be explored in considerable depths, the most relevant questions have been narrowed to those pertaining to this study's specific research objectives. Accordingly, the alternative hypotheses generated from those questions are as follows:

- Ha_1: The RAPTOR interface leads to better levels of SA than the U.S. Army's FBCB2 interface.
- Ha_2: The RAPTOR interface supports better decision-making processes than the U.S. Army's FBCB2 interface.

- Ha_3: The RAPTOR interface requires less cognitive workload than the U.S. Army’s FBCB2 interface.

III. METHOD

A. EMPIRICAL STUDY OVERVIEW

1. Research Design

A controlled laboratory experiment was used to assess military decision-maker performance while performing critical battlefield activities (e.g., acquiring and analyzing critical knowledge on the effects of terrain; assessing anticipated enemy actions on friendly force operations). This study was a 2 x 2 factorial mixed subjects design comparing two interfaces (RAPTOR and Baseline) and two tactical scenarios (attack and raid). Participants were randomly assigned to four groups (RAPTOR Group 1, RAPTOR Group 2, Baseline Group 1, and Baseline Group 2). Each group conducted both tactical scenarios using only one type of interface (i.e., groups were blocked against one type of interface). The Tactical scenario–interface combinations were counterbalanced to control for an order effect. Figure 17 illustrates the design used for this study.

2 x 2 Mixed Design		SCENARIOS	
		Attack	Raid
BLOCKS	RAPTOR 1	Trial 1	Trial 2
	RAPTOR 2	Trial 2	Trial 1
	Baseline 1	Trial 2	Trial 1
	Baseline 2	Trial 1	Trial 2

Figure 17. Research Design Example.

Participants were shown U.S. Army BN-level tactical operation displays driven by an interactive simulation technology, the Distributed Dynamic Decision-Making (DDD 4.0). Each tactical scenario lasted 25 minutes in duration. Participants played the role of a BN commander, and performed various activities associated with the C^2 of multiple manuever elements. Numerous measurements were collected to gain insight into participant decision-making processes, SA, and cognitive workload as they progressed through the scenarios.

2. Study Approach

As previously stated, when determining an interface's effectiveness at assisting the warfighter with maintaining SA and decision-making processes, one must employ a model that includes both human and machine. Accordingly, this study used the DMSC (Miller & Shattuck, 2006) as the theoretical framework to determine if RAPTOR enhanced human performance during the C^2 of tactical operations. Furthermore, this study also proposes the Tactical Rating of Awareness for Combat Environments (TRACE) tool (see Figure 18) as an evaluation strategy to determine levels of SA for the participants.

The DMSC model is composed of six ovals. The first three ovals represent technological contributions to the model, while the remaining three ovals represent human contributions to the model. Thus, data were captured for all six ovals during the study. Data from the RAPTOR interface representations and the DDD 4.0 simulation technology populated the first three ovals, while TRACE, CCIR, and critical event measures captured human data for the last three ovals. Table 1 lists the measures used to populate the ovals.

Table 1. Measures For Populating DMSC Ovals (After: Read, 2007).

Oval	Lab Experiment
1	DDD 4.0 Interactive Simulation Technology API Intelligence Agent Algorithms Network Data Storage
2	Combat Resource Parameters Combat Resource Capability Values Sensor Capability Values Probabilities Hit/Kill
3	Data Representations Displays and Other Graphical Screen Shots Interface Menus, Tools, and Options
4, 5, 6	TRACE Queries Commander's Critical Info Requirements Critical Event Criteria Audio and Video Recording Devices

3. Independent Variables

- Interface Type – RAPTOR and Baseline.
- Tactical Scenarios – attack and raid.

4. Dependent Variables

- TRACE Scores – accuracy of participant responses to periodic situation reports (SITREP) initiated by researchers to query for levels of SA.
- TRACE Latency – the elapsed time from when the researcher requests the participant to send a SITREP to when the participant answers all line item entries.
- Critical Event Latency – the elapsed time from when decision point criteria are met to when the participant announces decision point criteria have been met.
- Critical Information Latency – the elapsed time from when a commander's critical information requirement (CCIR) is available to when the participant reports the CCIR answer.
- Critical Information Scores – accuracy of participant responses to CCIR questions.
- Continuous Subjective Workload Assessment Technique – participant periodic entry of self-reported workload throughout the tactical scenarios.
- Total Requests for Information – total number of times a participant refers to an operation order during an entire scenario.

5. Study Setting

Data collection occurred at the Naval Postgraduate School (NPS) in Monterey, California. NPS contains a large pool of available U.S. Army Officers assigned to Maneuver, Fires, and Effects (MFE) basic branches. Officers assigned to MFE branches can be considered as experienced practitioners of C^2 since they receive professional education and extensive training on how to effectively operate the C^2 system, and also routinely perform C^2 activities during tactical operations.

6. Participants

Participants consisted of 16 male U.S. Army Officers with an average age of 36.8 years. Fourteen participants held the rank of 0-4, and two held the rank of 0-5. Fifteen

Officers had combat experience in either Iraq or Afghanistan, with an average time of 15 months in combat (SD = 8.6). Eight participants had operational experience with military operations other than war (MOOTW), with an average time of 4 months (SD = 4.3). The average number of deployments to combat zones and MOOTW was 1 (SD = 8.8). Fifteen participants conducted mission rehearsal exercises at a Combat Training Center (CTC). The average number of rotations to a CTC was 3 (SD = 1.8). Twelve participants had previous experience using a C^2 interface (i.e., FBCB2) either during tactical exercises or combat operations. Participants had no previous experience with either the RAPTOR interface or the Baseline interface. All participants had previous command experience, with an average of 29 months time in command (SD = 11.0). All participants had normal (or corrected) visual acuity and color perception. Participants were not given monetary compensation for their participation.

B. APPARATUS

1. Instrumentation

All experimental events were controlled by identical computers (Dell Precision M6300 laptops, Limerick, Ireland, 777 MHz), with identical color displays (Dell Computer, Limerick, Ireland, UltraSharp, 17", 1920 X 1200 resolution, Model WUXGA) with built-in standard QWERTY keyboards and Dell 2-Button USB Optical Mouse with scrolling wheel.

As stated earlier, tactical scenarios were presented to participants using the DDD 4.0 internet based simulation technology. Simulations were controlled through Aptima Inc.'s interactive client server. Scenario environmental conditions, friendly, and enemy activities were controlled by DDD 4.0's Agent Application Program Interface (API) intelligence algorithms. These algorithms standardized discrete activities to ensure participants encountered the same events during all scenarios.

Digital audio and video recording devices were used to collect participant data during all experimental events. Video recording devices consisted of 3 communication cameras (Canon, Oita, Japan, 16x zoom, 440,000 effective pixels, 47.5^{o} to 3^{o} view angle, 4.0 to 64.0mm minimum focus, Model VC-C4) that transmitted recorded video images directly to researcher laptops via Cat 5 Ethernet connections. Audio recording devices consisted of portable digital voice recorders (Olympus, Tokyo, Japan, WMA recording format, -70 dBv input level, 44.1 kHz sampling frequency, Model DS-50). Recorded video data were transferred to DVDs, and recorded audio file MP3 data were transferred onto researcher laptops for further analysis.

Participants were also provided with hard copies of the tactical operations orders, blank copies of the TRACE tool, a copy of the CCIR reporting format, a copy of the critical event reporting format, additional notepaper, a pen, and a calculator. Researchers collected completed TRACE tools and reporting formats at the conclusion of each experimental event for further analysis.

2. Materials

a. TRACE Tool

Since military practitioners are accustomed to gathering and disseminating friendly and enemy force assessments via situation report (SITREP) during tactical operations, the TRACE tool was developed to provide researchers with a method for minimizing obtrusive data collection. The TRACE tool is flexible enough to be applied to various types of experiments or training (simulated and/or field settings) that aim to measure levels of military practitioner SA during tactical situations. It was developed using different U.S. Army reports listed in *FM 101-5-2* (1999). These reports were refined for data collection purposes, and combined into a standard U.S. Army SITREP format (see Figure 18).

TRACE Tool

LINE 1 - Time	____________	(Engagement Clock Time)
LINE 2 - TF SLANT	____ / ____ / ____ / ____ Tanks (T) BFV (B) Mortars (V) Scouts (V)	(Operational Quantities)
LINE 3 - Enemy Strength*	Quantity	(ALIVE enemy equipment)
	T - 72 ____________	(Quantities)
(Report NONE, or	BMP ____________	(Quantities)
UNKNOWN if info is not	RPG TM ____________	(Quantities)
available at time of report)	SVBIED ____________	(Quantities)
LINE 4 - BDA Enemy*	Quantity	(DESTROYED enemy equipment)
	T - 72 ____________	(Quantities)
(Report NONE, or	BMP ____________	(Quantities)
UNKNOWN if info is not	RPG TM ____________	(Quantities)
available at time of report)	SVBIED ____________	(Quantities)
LINE 5 - BN Logistics	T/T ____________	(BN level resource statuses by COLOR)
	25 ____________	Color Conventions:
Formula:	Fuel (F) ____________	Green: 100% - 85%
QTY Resource On-hand / Full UBL	BFV (B) ____________	Amber: 84% - 70% Red: 69% - 50%
	Tanks (T) ____________	Black: 49% & Lower
LINE 6 - Assessment* (Report NONE, or UNKNOWN if info is not available at time of report)	____________	(Confirmed Enemy MLCOA or MDCOA)
LINE 7 - Your Actions	TF ____________	(List COA TF is CURRENTLY executing)
	TM A ____________	(NEXT task unit will execute IAW matrix)
	TM B ____________	(NEXT task unit will execute IAW matrix)
	TM C ____________	(NEXT task unit will execute IAW matrix)
	TM D ____________	(NEXT task unit will execute IAW matrix)
	Scouts ____________	(NEXT task unit will execute IAW matrix)
	Mortars ____________	(NEXT task unit will execute IAW matrix)

Figure 18. TRACE Tool Overview.

The TRACE tool was used to populate Ovals 4 to 6 of the DMSC with human SA data. TRACE measurements include timed responses to queries for specific information, and the accuracy of the information provided. As can be seen in Figure 18, queries for numerous types of friendly and enemy information are grouped under seven specific line item entries. This format provides participants with a logical sequence for reporting key pieces of information as they attempt to make sense of the battlefield situation. Lines 1-3 pertain to the historical activities of individual friendly and enemy elements on the battlefield. Participant responses to these queries provide information on Level 1 SA for populating Oval 4 (Perception). Lines 4 to 6 pertain to the current status of friendly and enemy capabilities. Participant responses to these queries provide information on Level 2 SA for populating Oval 5 (Comprehension). Line 7 pertains to immediate future friendly actions based on the overall battlefield situation. Participant responses to these queries provide information on Level 3 SA for populating Oval 6 (Projection).

To maintain consistent temporal references, TRACE measures were synchronized to simulation time and captured by the laptop computers presenting the simulations. TRACE measures were also captured by video recording devices focused on interface screens. Participants annotated their responses to line item entry queries onto hard copy TRACE tools, while their voice responses to the queries were captured by audio recording devices.

b. Commander's Critical Information Requirements (CCIR)

CCIR is a comprehensive list of information requirements identified by the commander to facilitate timely IM and the decision-making process that affect successful mission accomplishment (Department of the Army, 2004). CCIR is essentially a list of questions pertaining to enemy activities, friendly activities, and the environment that must be answered to enable the commander to maintain SA, project future activities, and make timely decisions (Department of the Army, 2003). As such, CCIR is normally comprised of two key subcomponents: priority intelligence requirements (PIR) and friendly force information requirements (FFIR).

Specific CCIRs (containing both PIRs and FFIRs) pertaining to each tactical scenario were provided to the participants (see Figures 19 and 20). As highlighted previously, scenario environmental conditions, friendly, and enemy activities were controlled by DDD 4.0's API intelligence algorithms which populated DMSC Ovals 1-2. Furthermore, these conditions and activities were presented to participants as graphical representations in the various interface displays which populated Oval 3. Participant temporal recognition of CCIR activities as they transpired on the battlefield were used to further populate Oval 4 (perception). Participant responses to CCIR queries were used to further populate Oval 5 (comprehension).

COMMANDER CRITICAL INFORMATION REPORT (CCIR) (Attack Scenario)

PIR # 1: Are *T-72 tanks* present vic *OBJ KILLER*?

LINE 1 -	PIR # 1	
LINE 2 - CCIR Answer	(YES / NO)	(Circle Yes or No)
LINE 3 - Time	______________________	(Engagement Clock Time)

PIR # 2: What is the enemy's remaining combat power for both *BMPs* & *T-72s* (**alive + anticipated**) once *TM D* reaches *ABF L*

LINE 1 -	PIR # 2	
LINE 2 - CCIR Answer	BMP ______________________	(QTY Alive **+** Remaining Anticipated / Templated)
	T-72 ______________________	(QTY Alive **+** Remaining Anticipated / Templated)
LINE 3 - Time	______________________	(Engagement Clock Time)

FFIR # 1: What is the friendly force ratio (ex. **3**:1) once *TM D* reaches *PL DAMAGE*?

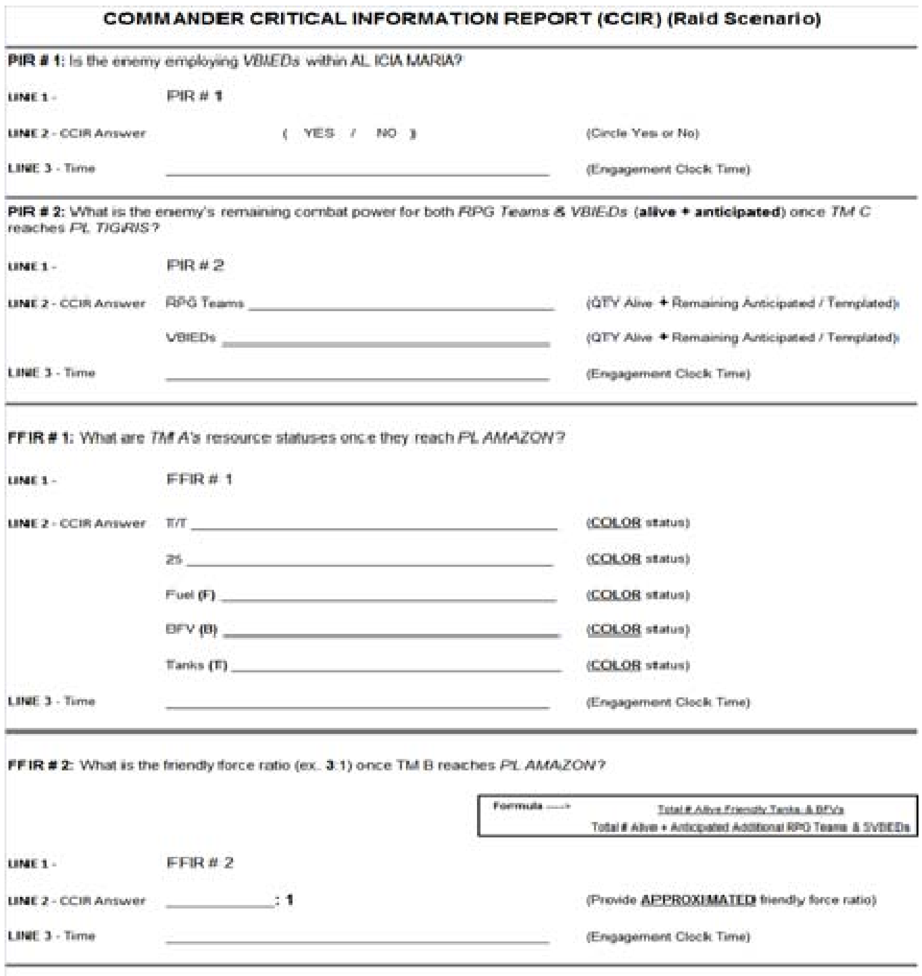
$$\boxed{\text{Formula} \longrightarrow \quad \frac{\text{Total \# Alive Friendly Tanks \& BFVs}}{\text{Total \# Alive + Anticipated Additional T-72s \& BMPs}}}$$

LINE 1 -	FFIR # 1	
LINE 2 - CCIR Answer	__________ **: 1**	(Provide **APPROXIMATED** friendly force ratio)
LINE 3 - Time	______________________	(Engagement Clock Time)

FFIR # 2: What are the *Mortar* platoon's resource statuses once they reach *PL DAMAGE*?

LINE 1 -	FFIR # 2	
LINE 2 - CCIR Answer	120 ______________________	(**COLOR** status)
	Fuel **(F)** ______________________	(**COLOR** status)
	M1064**(V)** ______________________	(**COLOR** status)
LINE 3 - Time	______________________	(Engagement Clock Time)

Figure 19. CCIR List and Report Format for Attack Scenario.



COMMANDER CRITICAL INFORMATION REPORT (CCIR) (Raid Scenario)

PIR # 1: Is the enemy employing *VBIEDs* within AL ICIA MARIA?

LINE 1 - PIR # 1

LINE 2 - CCIR Answer (YES / NO) (Circle Yes or No)

LINE 3 - Time ________________ (Engagement Clock Time)

PIR # 2: What is the enemy's remaining combat power for both *RPG Teams & VBIEDs* (**alive + anticipated**) once *TM C* reaches *PL TIGRIS*?

LINE 1 - PIR # 2

LINE 2 - CCIR Answer RPG Teams ________________ (QTY Alive + Remaining Anticipated / Templated)

VBIEDs ________________ (QTY Alive + Remaining Anticipated / Templated)

LINE 3 - Time ________________ (Engagement Clock Time)

FFIR # 1: What are *TM A's* resource statuses once they reach *PL AMAZON*?

LINE 1 - FFIR # 1

LINE 2 - CCIR Answer T/T ________________ (COLOR status)

25 ________________ (COLOR status)

Fuel (F) ________________ (COLOR status)

BFV (B) ________________ (COLOR status)

Tanks (T) ________________ (COLOR status)

LINE 3 - Time ________________ (Engagement Clock Time)

FFIR # 2: What is the friendly force ratio (ex. **3**:1) once TM B reaches *PL AMAZON*?

Formula ---> Total # Alive Friendly Tanks & BFVs / Total # Alive + Anticipated Additional RPG Teams & SVBIEDs

LINE 1 - FFIR # 2

LINE 2 - CCIR Answer ________ : **1** (Provide APPROXIMATED friendly force ratio)

LINE 3 - Time ________________ (Engagement Clock Time)

Figure 20. CCIR List and Report Format for Raid Scenario.

To maintain consistent temporal references, CCIR events were synchronized to simulation time, and were captured by both the laptop computers presenting the simulations and by video recording devices. Participants annotated CCIR queries onto CCIR reporting formats, and their voice responses were captured by audio recording devices.

c. Decision Points

As discussed earlier, *FM 6-0* (2003) describes decision making as selecting the one most favorable COA to accomplish a mission. Therefore, participants were provided three preplanned COAs and were expected to select one of them, based on their comprehension of the friendly and enemy force situation and activities (see Section D.1.). The decision to choose a specific COA was tied to critical event criteria listed in decision support matrixes that were provided to the participants as an annex in the tactical OPORDs (see Appendices A and B).

The point in time and space in which a participant was required to execute a specific COA was represented by a graphical control symbol known as a decision point (DP) (see below Section C.1.). *FM 101-5* (1997) describes DPs as critical events or locations on the battlefield where tactical decisions are required during mission execution. However, DPs do not dictate the decision to be made, only that a decision must be made, as well as when and where it should be made in order to have the maximum impact on friendly and/or enemy COAs.

Consequently, the availability of multiple COAs whose selection are dependent upon a participant's perception of critical events (or cues) represented by technological agents in a time constrained and uncertain environment is consistent with the NDM characteristics taken into account by the DMSC model (see Chapter II.3.C.). Critical events were controlled by DDD 4.0's API intelligence algorithms which populated Ovals 1 to 2, and were presented to participants as graphical representations in the various interface displays which populated Oval 3. Participant temporal recognition of these critical events were used to further populate Oval 4 (Perception), while their selection of a specific COA was used to further populate Oval 5 (Comprehension) and Oval 6 (Projection). Finally, COA selections provided insights for how participants expected events to unfold, and the accuracy of these decisions was represented by feedback loops from Oval 6 to Oval 2.

To maintain consistent temporal references, critical events were synchronized to simulation time, and were captured by both the laptop computers presenting the simulations and by video recording devices as well. Participants annotated critical event queries onto DP reporting formats, and their voice responses were captured by audio recording devices.

d. Workload

Adams et al. (1995) argues that acquiring and maintaining high levels of SA must be appreciated as an integral part of the operator's mental workload. Wickens (2008) further explains that an increase in workload can divert scarce cognitive resources from maintaining SA, while a well-designed usable display can both reduce workload and increase SA. However, Van Orden (2001) also suggests that a reduction in workload can lead to complacent behavior caused by increased operator reliance on technology and automation, which can also result in a loss of SA.

Accordingly, an estimation of workload commonly referred to as the continuous subjective workload assessment technique (C-SWAT) was incorporated to elicit participant perceived levels of workload during the experiment. The C-SWAT utilized is a simple, non-obtrusive workload estimation technique borrowed from previous workload studies conducted by Van Orden (2001). Like those studies, the 7 -point scale used in this study was also anchored only by the descriptors shown in Figure 21. The workload estimation appeared on the top portion of participant displays every 5 minutes during the 25-minute tactical scenarios. Audio prompts were incorporated to alert participants of the workload estimate's appearance. Participants entered their perceived level of cognitive workload once prompted.

Figure 21. Subjective Workload Estimation Prompt.

Researchers also annotated the number of times participants were forced to divide their attention between monitoring interface displays and accessing additional information located in hard copy tactical OPORDs as another simple workload measure.

C. INTERFACES

Interface displays, menus, tools, options, data representations, and other various graphical screen shots described previously in Chapter II.D (RAPTOR design), and during the following description of the baseline interface, were used to populate DMSC Oval 3.

1. RAPTOR Interface

Chapter 2 provides detailed explanations of the displays and functions associated with the RAPTOR interface. Participants using RAPTOR were permitted to use most of the interface tools and options previously described, and to incorporate data provided by the various displays as they executed C^2 activities during the tactical simulations. However, participants were unable to manipulate synchronization points represented in the spatial and temporal synchronization displays. Participants were also unable to manipulate the “Preview” mode to view pre-planned actions in time and space, but were able to access the “Review” mode to view historical activities. Additionally, friendly combat resource icons were held constant at the company level hierarchy, and the magnification reticule was disabled. Holding these tools constant standardized friendly force actions across each simulation, which ultimately enabled researchers to better control for unanticipated outcomes and to gather more meaningful measurements.

2. Baseline Interface

An alternative interface (Baseline) was developed in order to compare participant performance with the RAPTOR interface. The baseline interface was modeled after the U.S. Army’s FBCB2 interface. Although the baseline interface’s appearance, displays, tools, and options are not exactly the same as those provided by FBCB2, their functionality and informational structures are comparable (see Figure 22). For instance, like FBCB2, the baseline interface requires users to operate various command lines and pull-down menus to access different types and levels of data. Also like FBCB2, much of the data represented by the baseline interface are presented in alphanumeric (i.e., text) formats.

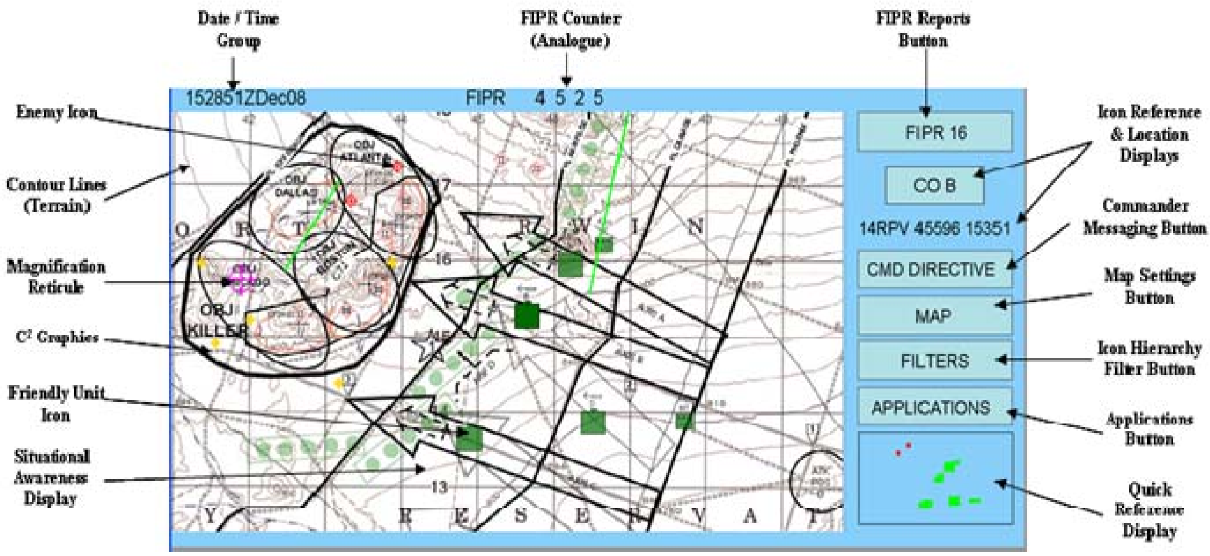


Figure 22. Baseline Interface (main screen).

A more concrete example of these similarities is illustrated by the activity sequence required to obtain combat resource values (e.g., percent of available fuel) at the BN level when using the baseline interface. This sequence is analogous to the activity sequence required when using FBCB2 as described by Talcott et al. (2007). Combat resource data can be obtained by activating the "FIPR" reports button located on the right side of the screen (see Figure 22). The button is clicked to access the "FIPR" menu, which provides a series of reports categorized by precedence and "filed" under flash, immediate, priority, and routine (FIPR) tabs. Combat resource reports (i.e., LOGSTAT Reports) are accessed by clicking on the "Routine" tab (see Figure 23).

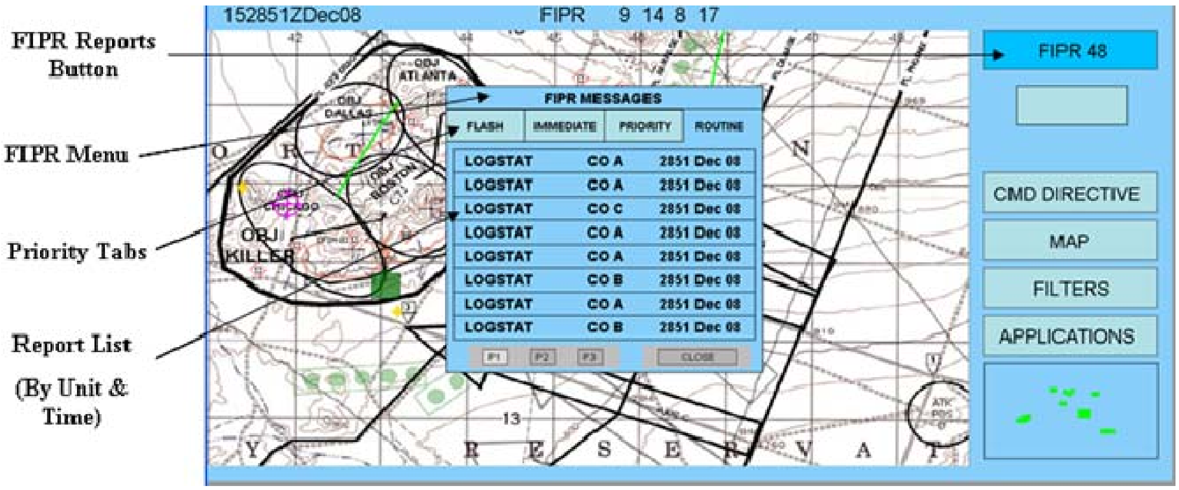


Figure 23. FIPR Menu for Baseline Interface.

Detailed combat resource data can be obtained by activating a Company level report (e.g., CO B) listed under the routine tab, which produces a pre-formatted report screen containing an alphanumeric data sheet (see Figure 24). The desired parameter value must be located within the alphanumeric data and either manually recorded or remembered. This process must then be repeated for each Company element within the Battalion level organization, followed by the computation of the aggregate parameter value (either manually or mentally).

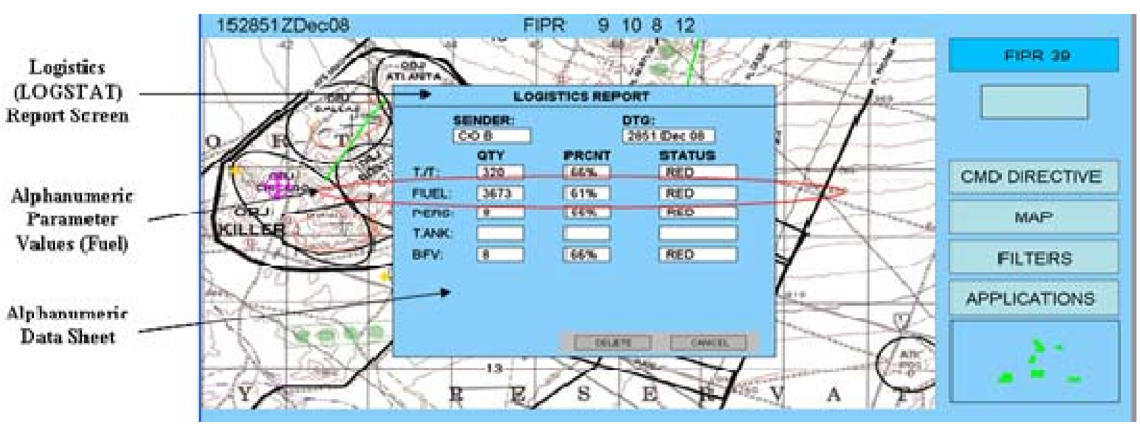


Figure 24. Logistical (LOGSTAT) Report Example (e.g., CO B).

FBCB2 enables users to generate and send numerous types of reports and "long form" combat messages (i.e., e-mails) to multiple platforms networked within the tactical internet. FBCB2 users can also determine the level of precedence for each report and combat message they send. However, according to Talcott et al. (2007), field studies of the FBCB2 interface conducted by the Center for Army Lessons Learned (CALL) indicate that commanders and their staffs tend to become inundated by the amount of data presented and the amount of effort required to interpret these data. This is particularly true during combat situations when high stress and heavy workloads are imposed. Therefore, for simplicity purposes, the baseline interface in the present study provides participants with only four types of tactical reports "generated" by subordinate units. Furthermore, each of these reports are generated based on predetermined events, categorized by fixed levels of precedence, organized by unit and reporting time, and displayed in standardized formats to provide participants with a more efficient process for selecting, interpreting, and integrating the data provided. Figure 25 illustrates the fixed levels of precedence categories and the predetermined generating events for each tactical report. Figure 26 illustrates the standardized alphanumeric formats used for each tactical report.

Report Type	Precedence Category	Generation Event
Contact Report	Flash	Only during the initial contact with an enemy element
Spot Report (SPOTREP)	Immediate	As new enemy forces are identified
Enemy Battle Damage Assessment Report (E-BDA)	Priority	As enemy combat resources are destroyed
Logistics Report (LOGSTAT)	Routine	As company level combat resources change

Figure 25. Tactical Report Methodology.

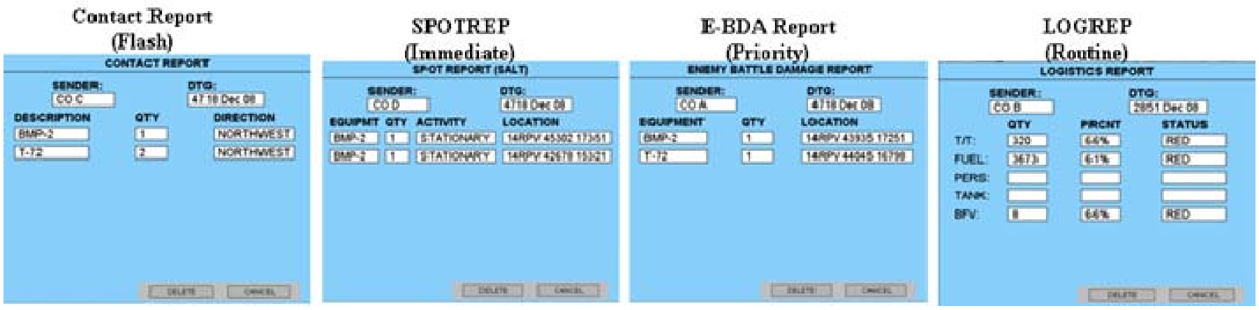


Figure 26. Standardized Report Formats for the Baseline Interface.

The RAPTOR and baseline interface designs are substantially different, but their informational content is equivalent. In other words, much of the data and hierarchical relationships represented by the RAPTOR interface are also represented by the baseline interface, though these representations are presented in different formats and styles. This informational equivalence ensured that comparisons between the RAPTOR and baseline interface were more meaningful. The following list briefly summarizes baseline interface functions, tools, and displays:

- **Situational Awareness Display** (see Figure 22) – provides representations for terrain, friendly unit icons, and enemy icons in the same manner as RAPTOR's Spatial Synchronization Display. The primary difference between these two displays is that the friendly unit icons presented in the baseline display do not change colors corresponding to their categorical status.

- **FIPR Reports** (see Figure 26) – Contact reports and SPOTREPs provide users with enemy specific data such as equipment type (e.g., tanks and APCs), location, and activity. E-BDA reports provide data on disabled enemy resources by specific type. These three reports provide alphanumeric data that is equivalent to the enemy data represented in RAPTOR's Enemy Resource Display. Furthermore, the LOGSTAT reports provide detailed alphanumeric data on the same resources that are represented in RAPTOR's Friendly Combat Resource Display. The

- **Command Directive Button** (see Figure 22) – clicking on the command directive button activates a screen with radio buttons that enables users to select pre-planned, alternate COAs (see Figure 27). This function is similar to the COA buttons located on the bottom of RAPTOR's screen. However, unlike RAPTOR, baseline interface users are not able to preview alternative COAs. Clicking and executing a COA radio button in the command directives menu directs subordinate elements to conduct the COA selected.
- **Applications Button** (see Figure 20) – clicking on the applications button activates a screen with radio buttons that enable users to display enemy and friendly weapon envelopes (see Figure 28). This function is similar to the control buttons located on the top of RAPTOR's screen.

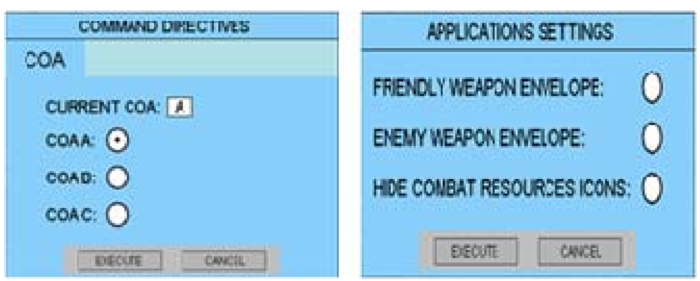


Figure 27. Additional Baseline Interface Options and Tools.

Conversely, RAPTOR provides certain forms of data that are not represented by the baseline interface. Examples of these are the temporal synchronization display, the alternative COA review buttons, and the force ratio display. However, these data are provided to participants in each tactical scenario's OPORD. Specifically, Annex C for each OPORD provides a synchronization matrix (see Appendices A and B) that meshes subordinate unit tasks with higher-level purposes that assists users with anticipating and coordinating combat activities. Annex C for each OPORD also provides alternative COA concept sketches (see Appendices A and B) that enables users to review preplanned, alternative COAs. Furthermore, force templates depicting the enemy's most likely COA (MLCOA) and most dangerous COA (MDCOA) are located in each OPORD's situation paragraph (i.e., Paragraph 1). Combining these enemy templates with the friendly force composition illustrated by Task/Organization charts located at the beginning of each OPORD enable users to calculate force ratio estimates (see Appendices A and B).

D. TACTICAL SIMULATION MODELS

Three tactical scenarios were developed for this study. The attack scenario is a simulated conventional high intensity conflict in desert terrain and was based on training exercises conducted at the U.S. Army's National Training Center at Fort Irwin, California. The raid scenario is a simulated counter-insurgency (COIN) low intensity conflict in urban terrain and was based on combat operations routinely conducted by U.S. Army forces in Iraq and Afghanistan. The defense scenario is a conventional high intensity conflict in desert terrain and was developed for training purposes only. The intent for incorporating the defense scenario was to familiarize participants with the functions, tools, and displays provided by either the RAPTOR or baseline interface while they conducted C^2 for a practice trial. The following sections provide a detailed description for the two scenarios (attack and raid) utilized during experimental events. The friendly and enemy activity data, resource values and parameters, algorithms, and representations described in this section were used to populate DMSC Ovals 1-3.

1. Friendly Situation

The friendly forces represented in each scenario consisted of a Battalion-sized element configured as a Task Force (TF). The TF maintained the same task-organization for each scenario, and consisted of four company teams (TM) and two specialty platoons (see Figure 28). TM A was mixed with eight Abrams tanks and four Bradley Fighting

Vehicles (BFV). TM B was pure with 12 Abrams tanks. TM C (mixed) contained eight BFVs and four Abrams tanks. TM D (pure) contained 12 BFVs. There were three platoons (Platoons 1, 2, and 3) in each TM, and each platoon consisted of four tactical vehicles (either all tanks or BFVs). The two specialty platoons remained under TF control and included a Mortar platoon consisting of four 120mm self-propelled mortars, and a Scout platoon equipped with four High Mobility Multipurpose Wheeled Vehicles (HMMWV).

TM A	TM B	TM C
1/A/Tank PLT	1/B/Tank PLT	1/C/Mech IN PLT
2/A/Tank PLT	2/B/Tank PLT	2/C/Mech IN PLT
3/C/Mech IN PLT	3/B/Tank PLT	3/A/Tank PLT
TM D	**TF Mortars**	**TF Scouts**
1/D/Mech IN PLT	A/Sec (2 x 120mm)	A/Wheeled Sec
2/D/Mech IN PLT	B/Sec (2 x 120mm)	B/Wheeled Sec
3/D/Mech IN PLT		

Figure 28. Friendly Force Task-Organization Chart.

The TF mission during the attack scenario was to destroy enemy forces located within the TF's battlespace. Tactical tasks included locating the forward edge of the enemy's obstacle belt, establishing an attack by fire position with TM D, establishing multiple breach lanes through the enemy obstacle belt, conducting a forward passage of lines, and completing the destruction of enemy forces within a specified objective.

Three possible friendly COAs were planned for the attack scenario. The implementation of a given COA was dependent upon specific critical event criteria being met at a DP. The first TM to establish a breach lane through the enemy obstacle belt was the DP criteria for the attack scenario (see Figure 29). COA A (the default COA) was predicated on TM B establishing the first breach lane, and planned for TM D to assault the objective from the center. COA B (the preferred COA) was predicated on TM C establishing the first breach lane, and planned for TM D to assault the objective from the south. COA C was predicated on TM A establishing the first breach lane, and planned for TM D to assault the objective from the north.

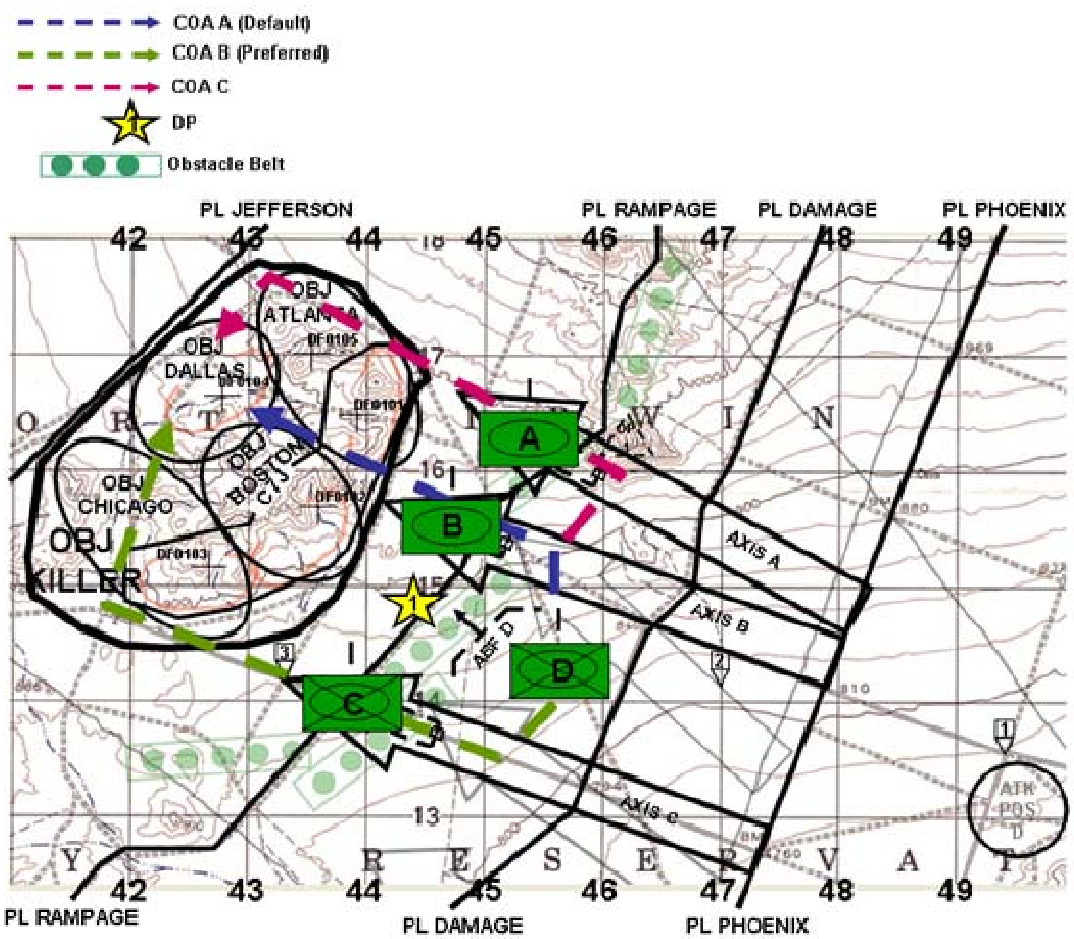


Figure 29. Courses of Action for Attack Scenario.

The TF mission during the raid scenario was to disrupt enemy insurgent operations within the fictional town of Al Icia Maria. Tactical tasks included conducting raids against multiple specified objectives, destroying insurgent activity centers, clearing numerous avenues of approach, neutralizing a high value individual (HVI), and exfiltrating from the battlespace.

Three possible friendly COAs were also planned for the raid scenario. The DP criteria for implementing a given COA in this scenario was dependent upon the HVI's location within the battlespace (see Figure 30). COA A (the default COA) was predicated on the HVI being located at Objective Dylan and required TM D to neutralize the HVI while TM B completed the enemy disruption by raiding Objective Bruce. COA B was predicated on the HVI not being located within Al Icia Maria, and required TM C to complete the enemy disruption by raiding Objective Bruce. COA C (preferred COA) was predicated on the HVI being located in the vicinity of Objective Bruce, and required TM A to neutralize the HVI at Objective Bruce.

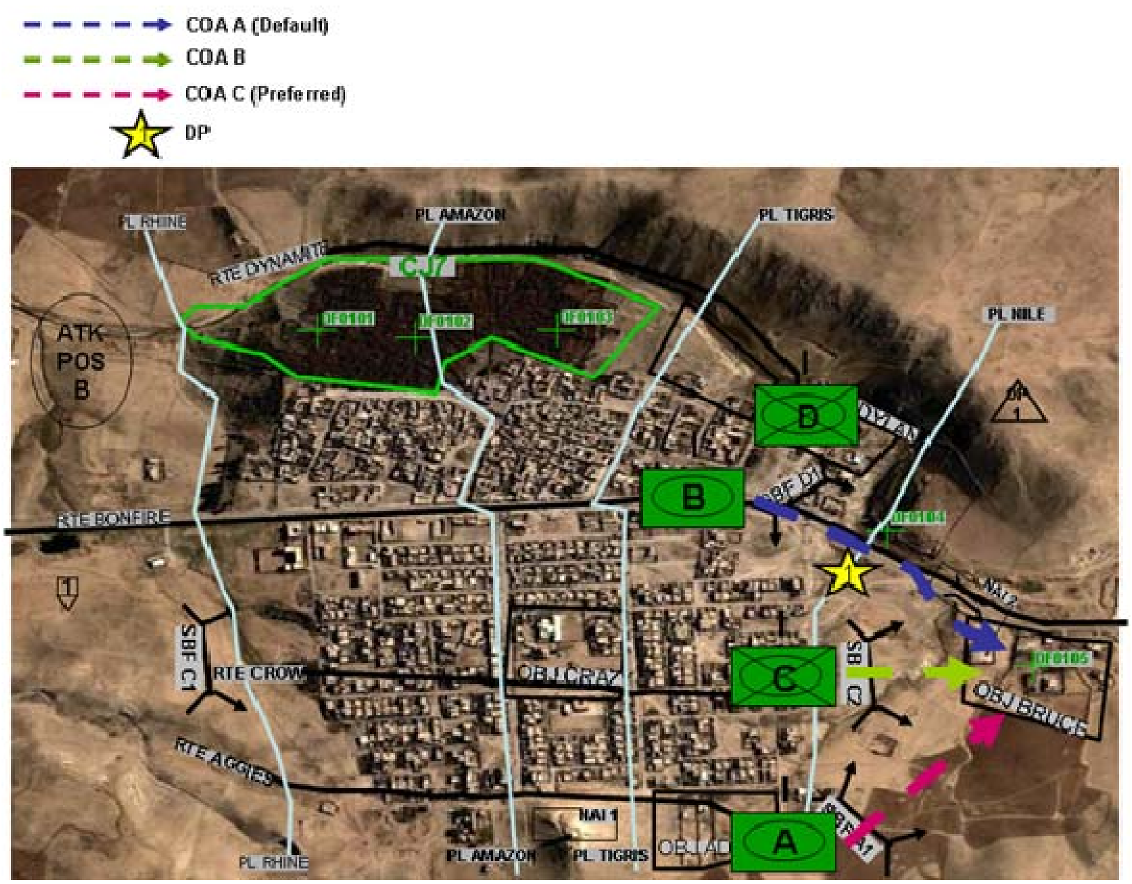


Figure 30. Courses of Action for Raid Scenario.

Both scenarios portray the friendly missions as ongoing combat operations. Thus, the TF had to execute their assigned tactical tasks with reduced combat resources. This constraint required participants to manage resource expenditures, and to maintain awareness of combat resource statuses down to the CO level to ensure goals were achieved. Table 2 depicts the initial and projected categorical resource statuses at the CO and PLT levels, and the initial parameter values established for individual combat resources at the beginning of both scenarios.

Table 2. Combat Resource Chart for Tactical Scenarios (Friendly Forces).

Company Level Resource Status			Platoon Level Resource Status			Individual Resource Parameters *(Initial Values Only)*								
UNIT	CATEGORICAL		PLT	CATEGORICAL		VEHICLES			AMMO			FUEL (Gal)		
	Initial	Projected		Initial	Projected	Qty	%	Color	Qty	%	Color	Qty	%	Color
TM A			1st PLT (Tank)			4	100		132	83		1500	74	
			2nd PLT (Tank)			4	100		132	83		1500	74	
			3rd PLT (BFV)			4	100		2552	69		540	77	
TM B			1st PLT (Tank)			4	100		132	83		1500	74	
			2nd PLT (Tank)			4	100		132	83		1500	74	
			3rd PLT (Tank)			4	100		132	83		1500	74	
TM C			1st PLT (BFV)			4	100		2552	69		540	77	
			2nd PLT (BFV)			4	100		2552	69		540	77	
			3rd PLT (Tank)			4	100		132	83		1500	74	
TM D			1st PLT (BFV)			4	100		2552	69		540	77	
			2nd PLT (BFV)			4	100		2552	69		540	77	
			3rd PLT (BFV)			4	100		2552	69		540	77	
			TF Mortars			4	100		140	51		280	74	
			TF Scouts			4	100		680	85		100	100	

As can be seen in Table 2, friendly combat resources consisted of tanks, BFVs, mortars, HMMWVs, ammunition, and fuel. Four of these parameters (tanks, BFVs, mortars, and HMMWVs) were computed as a simple percentage of the full complement. For simplification purposes, individual unit commander and executive officer vehicles were not included in the scenarios. Ammunition was computed as the number of potential armored vehicle and prepared defensive position kills (120mm tank rounds, 120mm mortar rounds, anti-tank missiles, 25mm rounds, and 40mm grenades). Fuel was computed as the range in kilometers, and consumption rates were based on each individual vehicle's fuel economy. Though RAPTOR is also designed to consider humans as a separate combat resource, personnel were included with the vehicles, and crewmembers were considered expended as friendly vehicles were destroyed.

2. Enemy Situation

Unlike the friendly forces, enemy force composition and capabilities were not the same for the two scenarios. This was due to the different operational environments and conditions used to create the simulation models (conventional high intensity conflict in open desert terrain vs. COIN low intensity conflict in urban terrain). The enemy also faced numerical and technological disadvantages on both battlefields. Therefore, enemy forces employed other types of "low-tech" weaponry to close these disadvantageous "gaps" in both scenarios.

The enemy force represented in the attack scenario consisted of a CO(+) sized element. Their composition included three PLTs of infantry fighting vehicles (BMP-2) reinforced by one PLT of T-72 tanks. Each PLT consisted of three tactical vehicles (either all tanks or BMP-2s). The enemy's command vehicle (BMP-2) was also present on the battlefield. Figure 31 illustrates the enemy composition for the attack scenario.

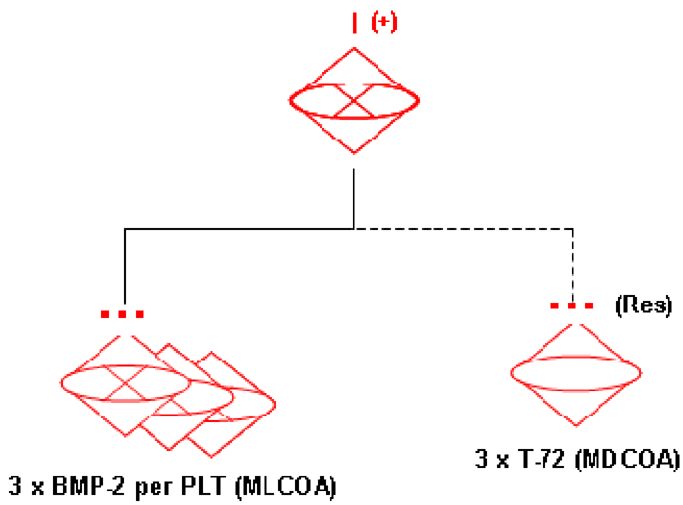


Figure 31. Enemy Composition Diagram (Attack Scenario).

The enemy mission during the attack scenario was to deny friendly forces the ability to attack west. The enemy conducted a defense in depth from dug-in fighting positions to increase their survivability. They employed their reserve T-72 tank platoon on the battlefield and conducted a counter-attack into the friendly force's exposed northern flank (see Figure 32). The enemy also established a large complex obstacle belt consisting of antitank mines and concertina wire to reduce friendly force numerical superiority.

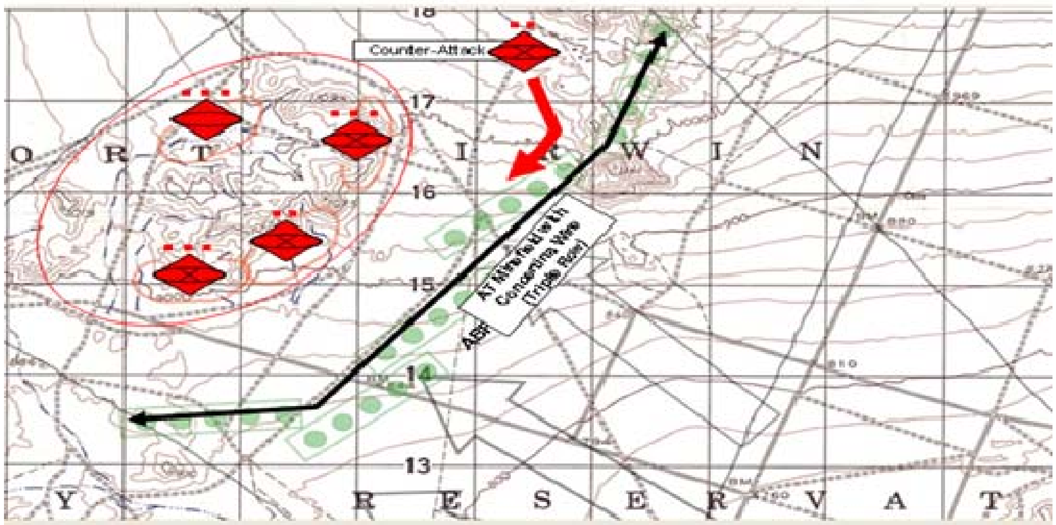


Figure 32. Enemy Most Dangerous COA (Attack Scenario).

The enemy force represented in the raid scenario also consisted of a CO(+) sized element. However, unlike the attack scenario, the enemy in the raid scenario is an unconventional insurgent force operating either as individuals, or in small teams consisting of 3-4 personnel. Lone enemy elements employed suicide car bomb attacks using vehicle borne improvised explosive devices (VBIED). Enemy teams conducted anti-armor ambushes and limited indirect fire attacks. Figure 33 illustrates the enemy composition for the raid scenario.

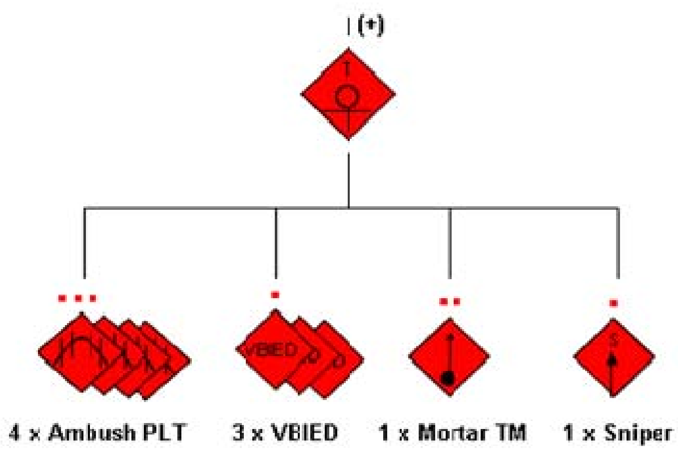


Figure 33. Enemy Composition Diagram (Raid Scenario).

The enemy mission during the raid scenario was to enable the HVI to exfiltrate from the battlespace by delaying friendly force penetration into insurgent support zones. The enemy conducted multiple anti-armor ambushes from prepared fighting positions located within several structures to increase their survivability. The enemy attacked friendly forces with VBIEDs and indirect mortar fires (see Figure 34). The enemy also employed anti-tank mines and numerous improvised explosive devices (IED) (i.e., roadside bombs) to reduce friendly force numerical and technological superiority.

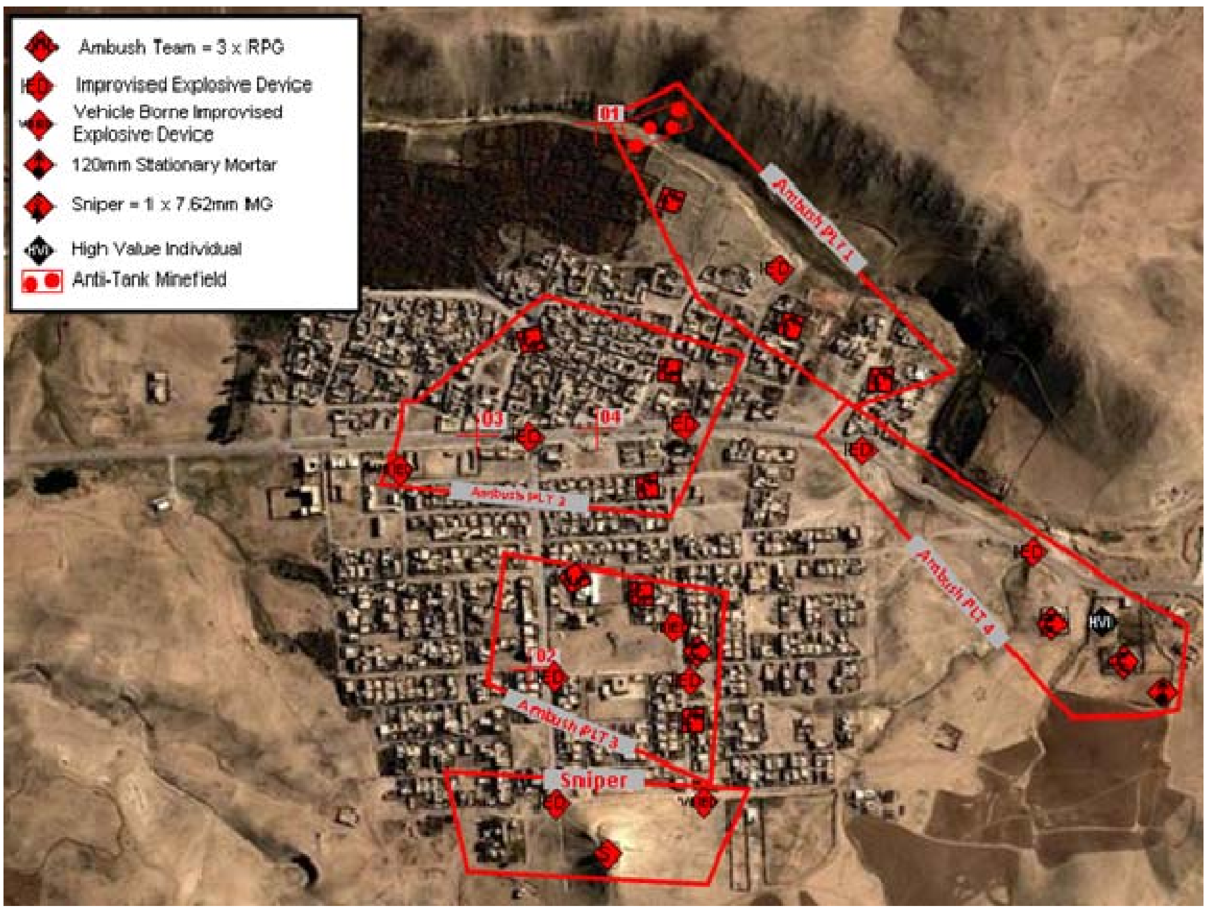


Figure 34. Enemy Most Dangerous COA (Raid Scenario).

Enemy combat resources represented in RAPTOR's enemy combat resource display consisted of tanks and BMP-2s for the attack scenario. VBIEDs and anti-armor ambush teams were represented in the display for the raid scenario. For simplicity purposes, VBIEDs were given T-72 tank force equivalence, and the anti-armor ambush teams were given BMP-2 force equivalence. IEDs and antitank mines possessed equivalent lethality. However, enemy ammunition and fuel values were not included.

3. Other Simulation Data

Detailed friendly and enemy capability data (e.g., weapon ranges, weapon re-load times, vehicular speeds, etc.) were added to API intelligence algorithms to better replicate actions and conditions typically encountered in the physical environment. Vehicular fuel capacity, fuel economy, and ammunition combat loads were also added to more accurately calculate combat resource parameter values and expenditure rates (see Table 3).

Table 3. Capability Data Matrix (Friendly and Enemy).

	Armament	Range	Re-Load	Combat Load	Crew	Fuel	Economy	Speed: Cross Country	Speed: 10% Slope	Speed: 60% Slope
M1A1 TANK	120mm canon	2,000 m	7 sec	40	1 x CDR 1 x GNR 1 x DRVR 1 x LDR	504 gal	6 Gal per KM	30 mph	20 mph	4.5 mph
M2A2 BFV	25 mm Chain Gun	2,000 m	10 min	900	1 x CDR 1 x GNR 1 x DRVR 6 x Riflemen	175 gal	2.3 Gal per KM	35 mph	25 mph	8 mph
	TOW II	3,000	2 min	12						
M1064A3 MORTAR	120mm Mortar	7,000 m	5 sec	69	1 x CDR 2 x GNR 1 x DRVR 2 x LDR	95 gal	0.20 Gal per KM	30 mph	20 mph	10 mph
M1114 HMMWV	Mk-19 40mm Grenage Launcher	1,200 m	60 sec	200	1 x CDR 1 x GNR 1 x DRVR	25 gal	0.08 Gal per KM	25 mph	15 mph	10 mph
T-72 TANK	125mm canon	2,000 m	12 Sec	52	1 x CDR 1 x GNR 1 x DRVR	N/A	N/A	35 mph	20 mph	8 mph
BMP 2	30mm Chain Gun	2,000 m	12 sec	52	1 x CDR 1 x GNR 1 x DRVR 7 x Riflemen	N/A	N/A			
Ambush TM	RPG 7 Grenade Launcher	300 m	4 sec	10	4					

Probability kill (P_k) data was also added to the tactical simulation models. As can be expected, friendly forces were more survivable and lethal than enemy forces in the tactical scenarios. However, the P_k values established for enemy forces were only slightly less than the P_k values established for friendly forces. This helped to better balance friendly versus enemy survivability and lethality. P_k algorithms consisted of a simple calculation for each individual weapon system's probability hit * each tactical vehicle's probability damage expectancy ($P_k = P_h * P_{de}$). Furthermore, a random number generator for kinetic exchanges between friendly and enemy vehicles was also incorporated to ensure one force did not possess an overwhelming survivability-lethality advantage over the other force. Table 4 illustrates the P_k values established for the tactical simulation models.

Table 4. Probability Kill Matrix (Friendly & Enemy).

FRIENDLY

M1A1 TANK			
System)			
Weapon Type	Front	Flank	Rear
125mm	0.23	0.3	0.36
VBIED	0.23	0.3	0.36
SPIGOT	0.28	0.35	0.42
30mm	0	0	0
RPG-7	0	0	0
AT Mine	Track Strike Only --> 0.55		
IED	Under --> 0.55		
Mortar	Direct Hit --> 0.006		

M2A2 BFV			
System)			
Weapon Type	Front	Flank	Rear
125mm	0.26	0.33	0.4
VBIED	0.26	0.33	0.4
SPIGOT	0.32	0.39	0.46
30mm	0.21	0.24	0.3
RPG-7	0.21	0.24	0.3
AT Mine	Track Strike Only --> 0.7		
IED	Under --> 0.7		
Mortar	Direct Hit --> 0.008		

M1064A3 MORTAR			
System)			
Weapon Type	Front	Flank	Rear
125mm	0.33	0.39	0.46
VBIED	0.33	0.39	0.46
SPIGOT	0.39	0.46	0.53
30mm	0.24	0.3	0.36
RPG-7	0.24	0.3	0.36
AT Mine	Track Strike Only --> 0.85		
IED	Under --> 0.85		
Mortar	Direct Hit --> 0.008		

M1114 HMMWV			
System)			
Weapon Type	Front	Flank	Rear
125mm	0.39	0.46	0.52
VBIED	0.39	0.46	0.52
SPIGOT	0.46	0.53	0.6
30mm	0.33	0.39	0.45
RPG-7	0.33	0.39	0.45
AT Mine	Wheel Strike Only --> 0.95		
IED	Under --> 0.95		
Mortar	Direct Hit --> 0.01		

ENEMY

T-72 TANK				
System)				
Weapon Type	Front	Flank	Rear	Dug-in
120mm	0.28	0.35	0.42	0.025
TOW II	0.38	0.42	0.49	0.05
25mm	0	0	0	0
40mm GL	0	0	0.012	0
Mortar	Direct Hit --> 0.006			

BMP-2				
System)				
Weapon Type	Front	Flank	Rear	Dug-in
120mm	0.35	0.42	0.49	0.035
TOW II	0.45	0.49	0.53	0.055
25mm	0.26	0.3	0.36	0.02
40mm GL	0	0.014	0.02	0
Mortar	Direct Hit --> 0.008			

AMBUSH TM	
Enemy Weapon	
Weapon Type	Bunker
120mm	0.4
TOW II	0.45
25mm	0.35
40mm GL	0.2
Mortar	0

E. PROCEDURES

Participants completed three sessions (training, trial event 1, and trial event 2) on successive days. As stated earlier, participants were randomly assigned to four groups (RAPTOR Group 1, RAPTOR Group 2, Baseline Group 1, and Baseline Group 2). Groups were blocked on one type of interface. The Tactical Scenario-Interface combinations were counter-balanced to minimize order effects. The following sections illustrate how each session was conducted.

a. Selection & Training

A convenience sample of volunteers was recruited from various departments within NPS. Each volunteer was provided with a brief description of the study and asked to complete at demographic survey (see Appendix C). Those volunteers who answered "yes" to colorblindness (question 6) were not included in the study. Upon completing the demographic survey and the consent form, participants were randomly assigned to an interface group, and scheduled for a training session.

Group training sessions (i.e., RAPTOR Interface training and Baseline Interface training) were conducted prior to the experimental trails. Participants only attended training for the type of interface to which they were assigned. Each training session lasted approximately one hour, and all participants received an oral tutorial of their respective interface, and a written and oral description of the simulations. Oral tutorials and descriptions were scripted to ensure consistency of instruction between the different groups. The tutorials familiarized participants on the menus, displays, tools, and functions offered by their assigned interface to minimize learning effects during the trials. Researchers conducted the tutorial using a pre-recorded PowerPoint presentation displayed by a 55-inch flat panel liquid crystal display.

Following the tutorial, participants conducted a practice tactical scenario (i.e., defense scenario) using their assigned interface to further minimize learning effects. Participants were given sufficient time to become comfortable with manipulating the various tools provided by their specific interface.

Once participants completed the practice scenario, researchers administered a brief knowledge test related to specific display options, tools, graphs, charts, etc. to ensure each participant retained the knowledge required for proficient use of their assigned interface type (see Appendix D & E). Proficiency was defined as a perfect score (100%) with every question answered correctly. Those participants who failed to score a 100% were provided with an opportunity to receive further training and to retake the knowledge test until they were proficient.

Upon successful completion of the knowledge test, participants were scheduled for their first trial. Participants were also provided with an advanced hard copy of the OPORD pertaining to the initial tactical scenario they would encounter to ensure they had adequate time to familiarize themselves with the scenario and to formulate any questions prior to conducting the trial.

b. Experimental Sessions

Participants conducted trials on an individual basis. Researchers provided the participant with a tabbed copy of the tactical OPORD, the TRACE tool, report formats, other associated materials, and general instructions for the trial once they arrived at the lab. Participants were given the opportunity to review the OPORD and receive clarification on mission specifics and anything else related to the conduct of the scenario. Participants then provided researchers with a mission back brief to ensure they understood the mission, commander's intent, information requirements, and key tasks to be executed during the simulation. Upon successful completion of the back brief, the participants conducted the 25-minute tactical scenario.

Participants were queried for specific levels of SA during three separate periods within the tactical scenarios. Each query was initiated by a pre-recorded audio prompt requesting a SITREP. The simulation paused at the beginning of the prompt, and participants were alloted five minutes to collect information for as many TRACE line item entries as possible. The simulation remained paused until participants reported answers for the line item entries they were able to complete. Participants were able to access data from the various interface displays and menus during the pauses. The purpose for these pauses was to enable participants to concentrate their efforts on collecting, integrating, and reporting queried information instead of being forced to divide their attention between preparing TRACE responses while also trying to monitor ongoing activities occuring on their screen. Upon completion of the SITREP, participants rated their perceived level of accuracy between 0% to 100% for their TRACE line item answers, then resumed the simulation by selecting the "done" button located on the bottom of their screen.

Participants were instructed to answer specific CCIRs as events transpired in the simulations. Each scenario contained four discrete CCIR activities that occurred at various times, phases, and locations throughout the tactical scenarios. Participants annotated and reported the activities once they perceived the cues. Unlike the TRACE queries, the simulations were not paused for CCIR reporting.

Participants were also instructed to report critical event criteria linked to DPs in the tactical scenarios. Each scenario contained one DP tied to three pre-planned COAs. Unlike the CCIR protocol described earlier, participants were not required to report each individual critical event as they occurred, but annotated and reported the decision made at a DP. In other words, decisions at a DP reflected participant comprehension for how the collective occurrence of critical events impacted the friendly and enemy situation, as well as their projection for how they expected future events to unfold. Participants simultaneously (or near simultaneously) executed the COA by selecting the corresponding COA button on their screen. Like the CCIR reporting, simulations were not paused during critical event decision reporting and COA selection. Critical event matrixes pertaining to each tactical scenario were provided to the participants as an annex in the tactical OPORDs (see Appendices A and B).

As discussed earlier, participants were asked to enter their perceived level of cognitive workload on the subjective workload scale when prompted. The scale was presented every five minutes during each 25-minute scenario, and remained active for 30 seconds. If a participant failed to enter their perceived workload within the 30 seconds allotted, the scale disappeared from the screen and the participant was assigned a "very high" (i.e., 7) score for that estimation period. The rationale behind this scoring technique was based on an assumption that the participant was too busy to momentarily divert their attention toward the estimation scale. The subjective workload estimation scale was presented to participants even when the simulation was paused for the TRACE queries to maintain consistency.

The OPORDs used for the experimental events were packaged in a three ring binder and tabbed for quick access to key information. Participants were allowed to reference an OPORD at any time during the scenarios, but were instructed to close the binder after they accessed the information of interest. Researchers annotated the number of times participants referenced an OPORD during a scenario as another simple workload measure.

Participants were scheduled for the follow-on trial immediately upon completing the initial event. The procedures for the subsequent trials were the same as those previously described.

Immediately following the second trial, participants assigned to the RAPTOR groups were asked to complete a brief feedback survey (see Appendix F). The purpose of this survey was to elicit participant concerns and perceptions about the different displays, options, and tools presented by the RAPTOR interface. Participant feedback was used to compile helpful recommendations aimed at improving RAPTOR's overall design and to develop a "way ahead" for future C^2 interface studies.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. RESULTS

The results consist of three parts: (1) statistical analysis for TRACE measurements; (2) statistical analysis for critical information and event measurements; and (3) statistical analysis for workload measurements. Summary and descriptive statistics are provided in parts a, b, and c for both the RAPTOR and Baseline interface user groups. Inferential statistics are used in all parts to analyze differences between levels of situation awareness, decision making, and workload with respect to query accuracy, latency times, C-SWAT inputs, and total requests for information between the RAPTOR and Baseline interface user groups.

A. STATISTICAL ANALYSIS FOR TRACE

1. TRACE Latency

Simulations were paused three times during each scenario for TRACE information collection and reporting. Latency was measured in seconds by calculating when the simulation paused to when the participant reported answers for completed line item and sub-line item entries. A t-test was performed to compare means between the two scenarios; there was no evidence that a learning effect had occurred as participants advanced from one trial to the next ($t(30) = 1.06$, $p = .29$). Combined mean TRACE times (i.e., attack + raid) were calculated for both RAPTOR and Baseline groups. The RAPTOR group responded more quickly with an overall mean latency time of 198.06 seconds (SD = 35.77), as compared to an average latency of 362.79 seconds (SD = 32.71) for the Baseline group (see Table 5).

Table 5. Descriptive Statistics for TRACE Latency.

	Baseline	*RAPTOR*
Mean	362.79	198.06
Standard Error	8.18	8.94
Median	363.67	197.00
Standard Deviation	32.71	35.77
Sample Variance	1069.81	1279.25
Kurtosis	-0.19	-0.15
Skewness	-0.35	-0.04
Range	121.00	132.00
Minimum	294.33	137.00
Maximum	415.33	269.00

Consistent with the research design, a mixed factor ANOVA was performed to test for differences within each group and between the two interfaces. Test results found that TRACE latency for the RAPTOR group was significantly less than the Baseline group ($F(1, 14) = 146.48, p < .0001$) (see Table 6).

Table 6. ANOVA Results for Between Interface TRACE Latency Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2516461.040	1	2516461.040	1697.943	.000
Interface Design	217086.136	1	217086.136	146.476	.000
Error	20748.900	14	1482.064		

Conversely, results also indicated that no significant differences existed within each group ($p = .16$), and did not yield evidence of a significant interface*scenario interaction ($p = .71$) (See Figure 35).

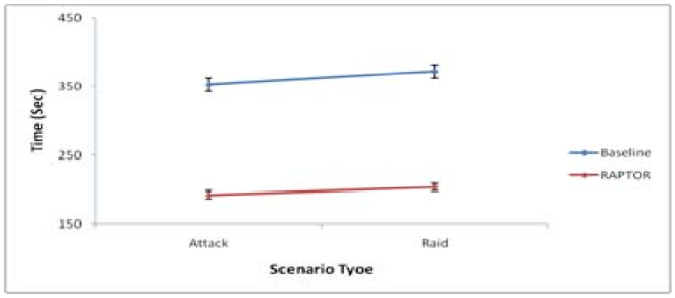


Figure 35. Estimated Marginal Means for TRACE Latency.

2. TRACE Accuracy

TRACE scores were calculated as correct or incorrect for each line item and sub-line item entry. Correct line item and sub-line item entries were summed to determine overall TRACE scores. Participants could score a maximum of 22 points per TRACE query if they answered all line item and sub-line item entries correctly. Another t-test was performed to compare means between the two scenarios. Results from this test also did not indicate a learning effect had occurred as participants advanced from one trial to the next (*t (29) = -0.60, p = .56*). The RAPTOR group was more accurate than the Baseline group with an overall mean TRACE score of 21.54 (SD = 0.53). In contrast, the Baseline group had an overall mean TRACE score of 11.87 (SD = 2.79). The small standard deviations coupled with the medians and modes being relatively close to the means suggest a small amount of variance amongst the TRACE scores (see Table 7).

Table 7. Descriptive Statistics for TRACE Scores

	Baseline	*RAPTOR*
Mean	11.87	21.54
Standard Error	0.70	0.13
Median	11.5	21.67
Mode	11.33	22
Standard Deviation	2.79	0.53
Sample Variance	7.78	0.28
Kurtosis	-0.71	-0.97
Skewness	0.37	-0.77
Range	8.67	1.33
Minimum	8	20.67
Maximum	16.67	22

Results from a mixed factor ANOVA found that TRACE scores for the RAPTOR group were significantly higher than Baseline group scores ($F(1, 14) = 130.14$, $p < .0001$) (see Table 8). No significant differences were found within each group ($p = .08$), and the interface*scenario interaction was also not significant ($p = .08$) (see Figure 36).

Table 8. ANOVA Results for Between Interface TRACE Score Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	8933.500	1	8933.500	1554.772	.000
Interface Type	747.781	1	747.781	130.143	.000
Error	80.442	14	5.746		

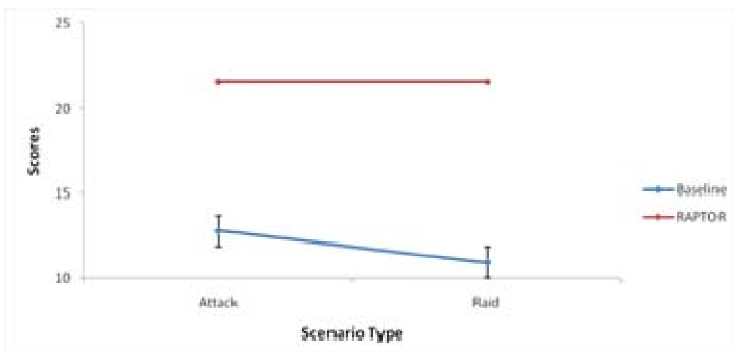


Figure 36. Estimated Marginal Means for TRACE Scores.

B. STATISTICAL ANALYSIS FOR CRITICAL INFORMATION AND EVENTS

1. CCIR Latency

Four cues pertaining to critical information requirements were presented during each scenario. Latency was measured in seconds from when the critical information was available to when the participant reported the CCIR answer. A t-test was used to compare means between the two scenarios; there was no evidence of a learning effect as participants advanced from one trial to the next (*t (29) = 1.28, p = .21*). Combined mean CCIR times (i.e., attack + raid) were calculated for both RAPTOR and Baseline groups. The RAPTOR group had the lowest overall mean latency time of 38.14 seconds (SD = 46.58) as compared to an average latency of 107.56 seconds (SD = 66.54) for the Baseline group (see Table 9).

Table 9. Descriptive Statistics for CCIR Latency.

	Baseline	*RAPTOR*
Mean	107.56	38.14
Standard Error	16.64	11.64
Median	98.13	30
Standard Deviation	66.54	46.58
Sample Variance	4427.80	2169.49
Kurtosis	-0.21	13.87
Skewness	0.84	3.61
Range	208.75	203.75
Minimum	28.75	4
Maximum	237.5	207.75

Researchers also performed a mixed factor ANOVA to test for differences within each group and between the two interfaces. Test results found that CCIR latency for the RAPTOR group was significantly less than the Baseline group (*F(1, 14) = 14.47, p = .002*) (see Table 10).

Table 10. ANOVA Results for Between Interface CCIR Latency Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	169835.205	1	169835.205	63.724	.000
Interface Design	38555.174	1	38555.174	14.466	.002
Error	37312.402	14	2665.172		

Results from the ANOVA also indicated that no significant differences existed within each group (*p = .64*), and did not yield a significant interface*scenario interaction (*p = .32*) (See Figure 37).

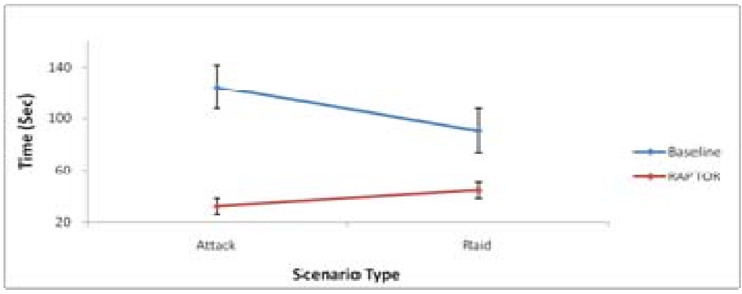


Figure 37. Estimated Marginal Means for CCIR Latency.

2. CCIR Accuracy

CCIR cues were treated as discrete activities. Answers for each of the four CCIRs presented per scenario were scored as either correct or incorrect. Thus, participants could score either 1 point per activity if they answered a CCIR query correctly or 0 points per activity if they answered a CCIR query incorrectly. The four scores were summed for each scenario with total possible outcomes ranging between 0-4 points. The RAPTOR group had the highest overall mean CCIR score of 3.81 (SD = 0.14) as compared to an average score of 2.13 (SD = 0.81) for the Baseline group. Once again, the small standard deviations coupled with the medians and modes being relatively close to the means suggest a small amount of variance amongst the TRACE scores (see Table 11).

Table 11. Descriptive Statistics for CCIR Scores.

	Baseline	*RAPTOR*
Mean	2.13	3.81
Standard Error	0.20	0.14
Median	2	4
Mode	2	4
Standard Deviation	0.81	0.54
Sample Variance	0.65	0.30
Kurtosis	0.75	9.09
Skewness	0.63	-3.03
Range	3	2
Minimum	1	2
Maximum	4	4

The data violated the normality assumption, thus a nonparametric permutation test was performed to compare outcomes between RAPTOR and Baseline groups. The test consisted of a simulation using *S-Plus* statistical software. During the simulation, observed samples (i.e., CCIR scores per participant) were randomly distributed between two groups of size eight 1,000 times to determine how often the re-sampled statistic of interest was as extreme as the observed value of -27. Results of the simulation demonstrated a difference as extreme as (+/-) 27 only one time out of 1,000, thus enabling the researchers to infer a statistically significant difference existed between the two interfaces. Figure 38 illustrates the difference of observed CCIR scores between the RAPTOR and Baseline interfaces.

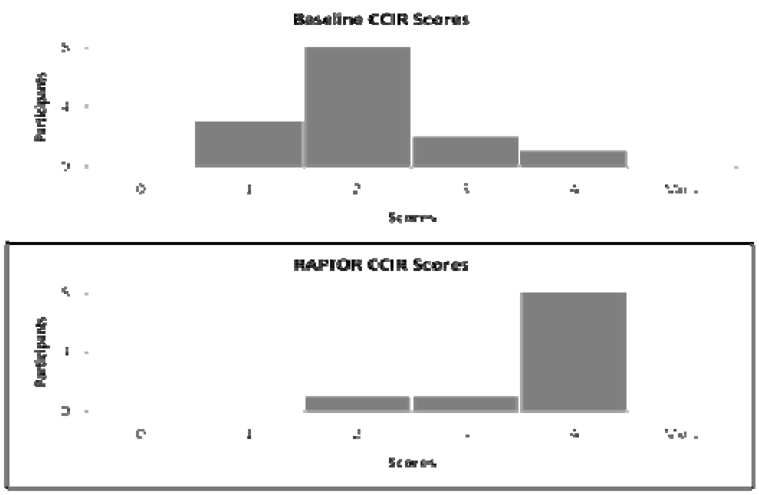


Figure 38. Graph of RAPTOR & Baseline CCIR Scores

3. Critical Event Latency

One decision point, the critical event, was located within each scenario. Critical event latency was measured in seconds from when all critical event criteria had been met at a decision point to when the participant selected a specific COA. Combined mean CCIR times (i.e., attack + raid) were calculated for both RAPTOR and Baseline groups. The RAPTOR group had the lowest overall mean critical event latency time of 81.19 seconds (SD = 63.01) as compared to an average latency of 94.27 seconds (SD = 32.63) for the Baseline group. However, the large standard deviation coupled with the median and mode being relatively far apart from the mean suggests a large amount of variance between times within the RAPTOR group (see Table 12).

Table 12. Descriptive Statistics for Critical Event Times.

	Baseline	*RAPTOR*
Mean	94.27	81.19
Standard Error	8.42	15.75
Median	95	58.5
Mode	119	16
Standard Deviation	32.63	63.01
Sample Variance	1064.50	3970.30
Kurtosis	-1.04	0.13
Skewness	0.04	0.92
Range	110	217
Minimum	43	4
Maximum	153	221

Furthermore, results from a mixed factor ANOVA found no statistical difference in critical event times between the two interfaces (*F(1, 14) = .127, p = .73*). Interestingly, test results did enable researchers to discover that a significant interface*scenario interaction existed (*F(1, 14) = 7.868, p = .02*) (see Figure 39).

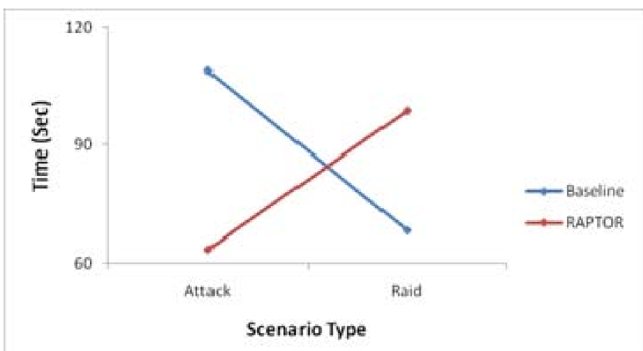


Figure 39. Estimated Marginal Means for Critical Event Latency.

C. STATISTICAL ANALYSIS FOR WORKLOAD

1. Continuous Subjective Workload Assessment Technique (C-SWAT)

Perceived levels of cognitive workload data were produced from participant entries on a 7-point Likert scale (i.e., 1 = very low workload, 7 = very high workload) every 5 minutes during each scenario. The RAPTOR group had the lowest overall mean C-SWAT entry of 2.53 (SD = 1.01) as compared to an average entry of 4.9 (SD = 1.00) for the Baseline group (see Table 13).

Table 13. Descriptive Statistics for C-SWAT Entries.

	Baseline	*RAPTOR*
Mean	4.9	2.53
Standard Error	0.25	0.25
Median	4.85	2.2
Mode	5.9	1.4
Standard Deviation	1.00	1.01
Sample Variance	0.99	1.02
Kurtosis	-0.86	-0.34
Skewness	0.02	0.74
Range	3.4	3.3
Minimum	3.1	1.4
Maximum	6.5	4.7

Since C-SWAT scores were ordinal, a Mann-Whitney test was performed to examine differences in C-SWAT means between the RAPTOR and Baseline groups. Test results found that C-SWAT scores for the RAPTOR group was significantly less than the Baseline group during both the attack (z = *-3.00, p = .003*) and raid (z = *-2.90, p = .004*) scenarios (see Table 14).

Table 14. Mann-Whitney Results for Mean C-SWAT Entry Differences.

	Attack	Raid
Mann-Whitney U	3.500	4.500
Z	-2.998	-2.899
Asymp. Sig. (2-tailed)	.003	.004
Exact Sig. [2*(1-tailed Sig.)]	.001[a]	.002[a]

Figure 40 further illustrates C-SWAT entry differences by scenario between the two interfaces.

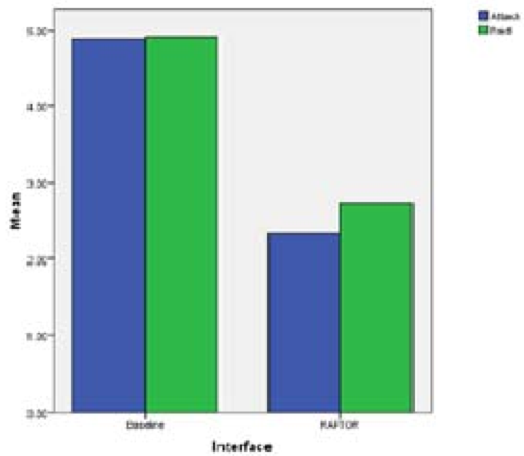


Figure 40. Average C-SWAT Scores for Baseline and RAPTOR Groups.

2. Requests for Information (RFI)

A tally was made for each time a participant referred to an OPORD during a scenario. These tallies resulted in a total RFI count at the end of each scenario. Combined mean RFI counts (i.e., attack + raid) were calculated for both RAPTOR and Baseline groups. The RAPTOR group had the lowest overall mean RFIs of 0.44 (SD = 0.51) as compared to an average RFI tally of 6.25 (SD = 1.65) for the Baseline group. Once again, the small standard deviations coupled with the medians and modes being relatively close to the means suggest a small amount of variance amongst the RFIs (see Table 15).

Table 15. Descriptive Statistics for RFI Counts.

	Baseline	*RAPTOR*
Mean	6.25	0.4375
Standard Error	0.41	0.13
Median	6	0
Mode	6	0
Standard Deviation	1.65	0.51
Sample Variance	2.73	0.26
Kurtosis	-0.11	-2.22
Skewness	-0.05	0.28
Range	6	1
Minimum	3	0
Maximum	9	1

A mixed factor ANOVA was used to test for differences within each group and between the two interfaces. Results found that the RAPTOR group had significantly fewer RFIs than the Baseline group (*F(1, 14) = 194.67, p < .0001*) (see Table 16).

Table 16. ANOVA Results for Between Interface RFI Count Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	357.781	1	357.781	257.695	.000
Interface Design	270.281	1	270.281	194.672	.000
Error	19.438	14	1.388		

Results from the ANOVA also indicated that a significant difference did exist within groups (*F(1, 14) = 13.51, p < .002*), but did not yield a significant interface*scenario interaction (*p = .10*) (See Figure 41).

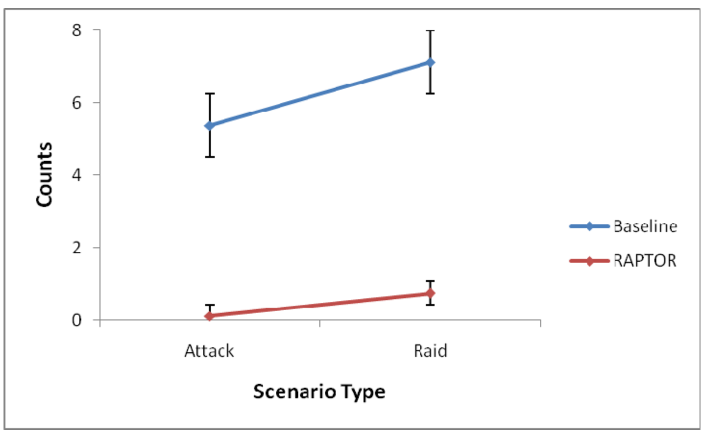


Figure 41. Estimated Marginal Means for RFI Counts.

D. STATISTICAL ANALYSIS FOR PERCEIVED VS. ACTUAL ACCURACY

Participants were asked to indicate their confidence they had in the accuracy of their TRACE line item answers during each simulation pause. This was called "Perceived Accuracy" and ranged from 0% to 100%. Actual accuracy data were produced from the total number of line item entries answered correctly. The RAPTOR group reported and achieved the highest overall mean accuracy percentage of 0.94 (SD = 0.04) and 0.98 (SD = 0.02) respectively (see Table 17).

Table 17. Descriptive Statistics for Perceived and Actual Accuracy.

	Baseline		RAPTOR	
	Perceived	*Actual*	*Perceived*	*Actual*
Mean	0.86	0.54	0.94	0.98
Standard Error	0.02	0.04	0.01	0.01
Median	0.87	0.52	0.94	0.98
Standard Deviation	0.07	0.10	0.04	0.02
Sample Variance	0.00	0.01	0.00	0.00
Kurtosis	3.03	-1.21	-1.28	2.95
Skewness	-1.52	0.00	0.25	-1.59
Range	0.22	0.29	0.12	0.07
Minimum	0.72	0.38	0.88	0.93
Maximum	0.93	0.67	1.00	1.00

Another mixed factor ANOVA was used to test for differences within each group and between the two interfaces. Results found that perceived and actual TRACE accuracy percentages for the RAPTOR group was significantly higher than the Baseline group ($F(1, 14) = 89.76, p < .0001$) (see Table 18).

Table 18. ANOVA Results for Between Interface Confidence Effects.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	21.978	1	21.978	3755.281	.000
Interface Design	.525	1	.525	89.756	.000
Error	.082	14	.006		

Furthermore, results from the ANOVA indicated that a significant difference existed within groups ($F(1, 14) = 54.06, p < .0001$), and that a significant group*accuracy interaction also existed ($F(1, 14) = 90.98, p < .0001$) (see Figure 42).

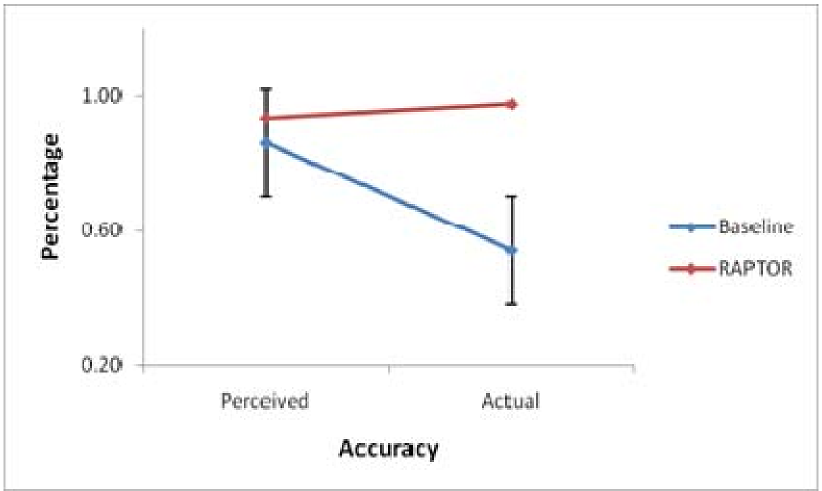


Figure 42. Estimated Marginal Means for Perceived and Actual Accuracy.

THIS PAGE INTENTIONALLY LEFT BLANK

V. DISCUSSION

This chapter discusses the implications of the results presented in Chapter IV and discusses why such significant findings consistently emerged. Key observations gathered from other researchers' work discussed throughout Chapter II are included to emphasize military relevance of the findings.

A. IMPLICATIONS OF ANALYSIS

1. Situation Awareness (Hypothesis 1)

- Ha_1: The RAPTOR interface leads to better levels of SA than the U.S. Army's FBCB2 interface.

The TRACE tool was developed to provide researchers with a non-obtrusive method for collecting participant SA data. TRACE latency and accuracy results show that RAPTOR users were able to answer TRACE queries significantly faster and more accurately than Baseline interface users, which supports the first hypothesis (see Figure 43).

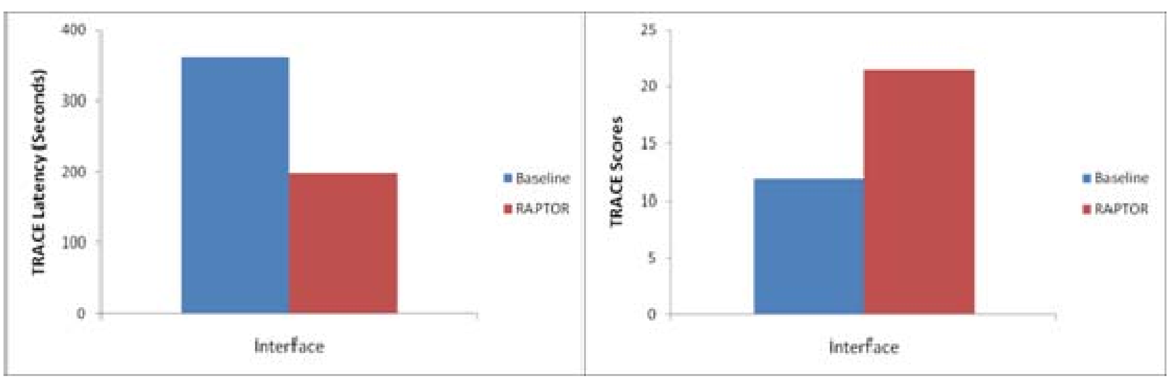


Figure 43. Combined TRACE Results (Latency and Accuracy).

Participant responses to TRACE queries were used to populate the Dynamic Model of Situated Cognition (DMSC) Ovals 4 to 6. As stated in Chapter II, answers to TRACE Lines 1-3 provided information on Level 1 SA for populating Oval 4

(Perception). Answers to Lines 4-6 provided information on Level 2 SA for populating Oval 5 (Comprehension), while answers to Line 7 provided information on Level 3 SA for populating Oval 6 (Projection). RAPTOR enabled participants to correctly answer an average of 21.54 out of 22 sub-line item queries in an average of 198 seconds. In contrast, Baseline interface participants correctly answered an average of only 11.87 sub-line item queries in an average of 363 seconds (see Tables 5 and 7). Baseline interface users were only able to perceive and gain limited comprehension for how deviations could potentially endanger current task achievement, while RAPTOR users required significantly less time to successfully forecast how future events would potentially impact objectives and end states. These findings directly support research conducted by Shattuck and Miller (2006) who found that the design of an interface can affect SA by representing the environment more or less accurately.

RAPTOR was designed to support direct perception by taking advantage of powerful human perceptual resources by presenting friendly, enemy, and environmental data in a meaningful, coherent, and structured manner (Rasmussen, 1992). Conversely, the Baseline interface did not appear to support direct perception. The Baseline interface presented complex data primarily through alphanumeric reports. While RAPTOR's design seemed to decrease the amount of cognitive resources required to acquire and integrate the data presented, the Baseline interface's design forced users to apply extensive cognitive resources to reason about situations. This inference is further supported by the ad-hoc tables and matrices created on notepaper by Baseline users during the experimental trials as a strategy to cope with task demands (see Appendix G). The successful results from this study strategy support Talcott et al.'s (2007) recommendation that the incorporation of an intact perception-action loop should be considered as a higher-order goal in interface designs.

Enhanced levels of SA, as demonstrated by RAPTOR users, contribute to flexible and agile forces that are capable of acting faster than the enemy (Bushey & Forsyth, 2006). Improved TRACE speed and accuracy help operators close the "information gap" which, according Endsley and Garland (2000), is an important criterion for assessing the benefit of any tactical C^2 system interface design.

2. Decision Making (Hypothesis 2)

- Ha_2: The RAPTOR interface supports better decision-making processes than the U.S. Army's FBCB2 interface.

a. Critical Information Inferences

Commanders Critical Information Report (CCIR) latency and accuracy results show that RAPTOR users were able to answer critical information queries significantly faster and more accurately than Baseline interface users, which supports the second hypothesis (see Figure 44).

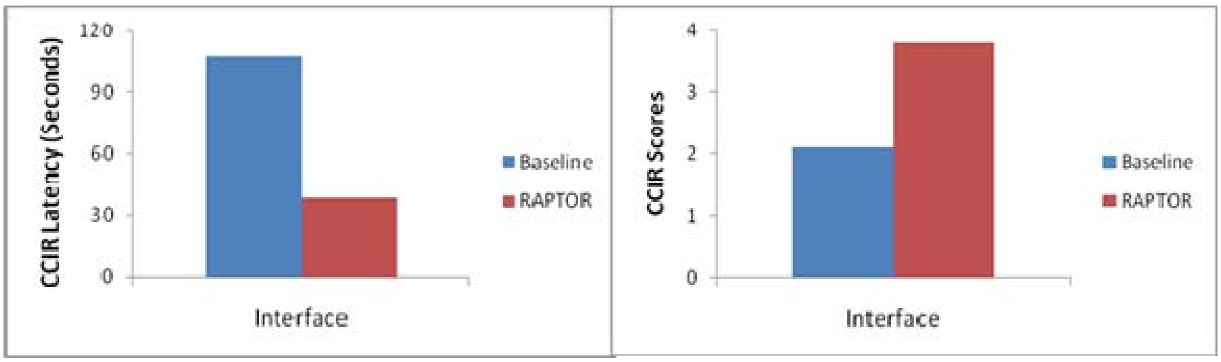


Figure 44. Combined CCIR Results (Latency and Accuracy).

Participant responses to CCIR queries are represented by feedback loops in the DMSC (see Figure 7). RAPTOR enabled participants to correctly answer an average of 3.8 out of 4 CCIR queries in an average of 38 seconds. In contrast, Baseline interface participants correctly answered an average of only 2.1 sub-line item queries in an average of 108 seconds (see Tables 9 and 11). The speed at which RAPTOR users were able to perceive and process critical information provided them with additional time to confirm or deny expectations. Again, these findings directly support research conducted by Shattuck and Miller (2006) who found that the design of an interface can affect decision making by representing the environment more or less accurately.

Reasons for these results can be attributed to the design principle of direct perception as previously described. However, RAPTOR was also designed to support direct manipulation, thereby maintaining intact perception-action loops and allowing operators to act directly on objects of interest in the interface (Talcott et al., 2007;

Bennett et al., 2008). In contrast, the Baseline interface design supports primarily indirect manipulation which results in inefficient action sequences (Talcott et al., 2007). This problem is especially evident when the map display is covered by the large pop-up windows (see Figures 23 and 24). Consequently, the findings generated by CCIR measurements support Shattuck et al.'s (2000) conclusions. That is, interfaces that make salient the most important data enables commanders to focus on significant portions of the battlefield and enables them to reason about situations in a more sophisticated manner.

With respect to military relevance, the speed and accuracy with which RAPTOR can enable commanders to identify and comprehend critical information requirements facilitates timely decision-making processes that potentially affect successful mission accomplishment (Department of the Army, 2004). The CCIR findings suggest that RAPTOR has the potential to enable commanders to operate within enemy decision making cycles, which will lead to agile forces capable of acting faster than the enemy.

b. Critical Event Inferences

Comparisons of critical event latency between the two interfaces were not significant. To provide participants with an opportunity to make decisions during the experimental trials, the researchers elected to draft tactical scenarios containing three COAs. One of these COAs had to be selected by the time friendly forces met all critical event criteria at a decision point. Only one decision point was located within each scenario. Unlike the TRACE or CCIR queries, no signals or mechanisms were incorporated into any of the interface displays to assist participants with making the decision. COA selections were based solely on participants understanding the criteria listed in scenario decision support matrices and their temporal recognition of critical events as they transpired in the battlespace. Consequently, no participants chose an incorrect COA.

This outcome may seem odd given the significant differences found in the levels of SA and critical information comprehension between the two interfaces.

However, this result does support Adams et al.'s (1995) finding that it is possible for commanders with minimal SA to implement timely and accurate decisions because their experience and training may be sufficient to offset degraded views of the situation as long as they understand task demands. All participants were very experienced C^2 practitioners, and all had been queried by researchers prior to conducting scenarios to ensure they fully understood the mission, commander's intent, information requirements, and key tasks to be executed during the simulations. Thus, individual participant experience, training, and scenario understanding, coupled with the scenarios containing only one decision point may have led to a ceiling effect.

Interestingly, results indicated a significant interface*scenario interaction. Essentially, Baseline interface users selected COAs during the raid scenario faster than RAPTOR users. On the surface, this outcome seems inconsistent with performance patterns demonstrated by Baseline users throughout all other tasks. However, when taking into consideration that all Baseline users had combat deployments to either Iraq or Afghanistan (from which the raid scenario was modeled), and all had previous FBCB2 experience, it is plausible to infer that the participants decided upon one COA prior to the decision point since the scenario was sufficiently representative of situations in which they had recent exposure and experience. This argument has implications for Klein's (1993) RPD model, which states that while under time pressure commanders rely on past experiences to select their COA.

3. Workload (Hypothesis 3)

- Ha_3: The RAPTOR interface requires less cognitive workload than the U.S. Army's FBCB2 interface

C-SWAT scores and RFI reference results show that cognitive workload was significantly less for RAPTOR users than Baseline interface users, which supports the third hypothesis (see Figure 45).

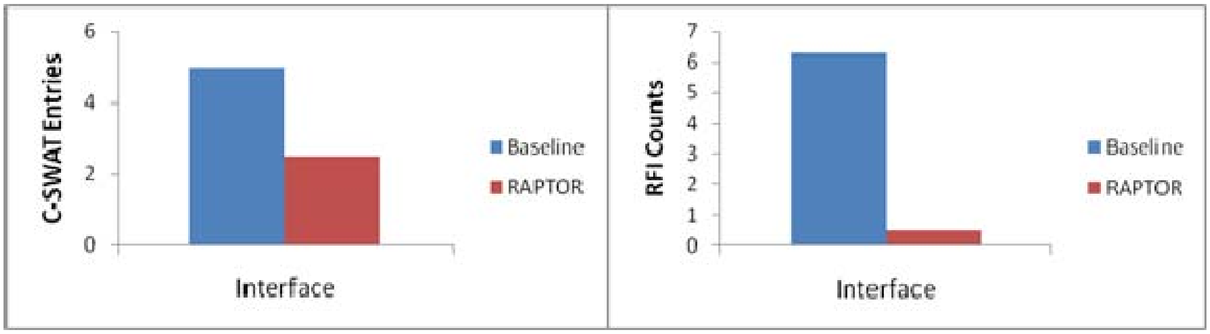


Figure 45. Combined Workload Results (C-SWAT and RFI).

Participant C-SWAT scores were used to measure self-reported cognitive workload. Participants using RAPTOR reported an average workload of 2.5 out of 7 (i.e., 1 = very low, 7 = very high). In contrast, Baseline interface participants reported an average workload of 5 (see Table 13). Researchers also annotated the number of times participants referenced an OPORD during the scenarios as an additional workload measure. The argument for using this measurement was that referring to external forms of information forced participants to divide their attention between monitoring interface displays and accessing additional information, which could contribute to increased workload. Participants using RAPTOR sought external information an average of 0.5 times per scenario. Conversely, Baseline interface participants sought external information an average of 6.3 times per scenario (see Table 15).

The design of RAPTOR was driven by the explicit consideration of the C2 work domain (Bennett, et al., 2008). Abstraction and aggregation hierarchies and SRK taxonomy principles (Vincente & Rasmussen, 1992) permitted RAPTOR users to capture critical data pertaining to tactical scenario goals, purposes, and constraints, because RAPTOR represented that information in the form of higher and intermediate levels of visual salience directly on the display (Talcott et al., 2007). Information presented in this manner enabled participants to focus on critical information (e.g., combat power, resources, time, task synchronization, and force ratios) without having to switch between multiple sets of displays. In contrast, the Baseline interface presented data primarily via alphanumeric reports, which forced participants to access numerous menus, tabs, and individual unit reports to gather the data. Unlike RAPTOR, whose individual displays provide users with continuously updated aggregate and categorical values of key data, Baseline interface users had to calculate numerous parameter values (either manually or mentally) after the necessary data were obtained (see Appendix G for examples of the ad-hoc tables and matrices created by Baseline users during the experimental trials). These results support Talcott et al.'s (2007) research which found that displays having aggregation and abstraction principles incorporated into their designs support human perception of information in time and space, ultimately reducing operator workload.

Researchers also found evidence of significant differences within groups for RFI results. Analysis revealed that RAPTOR and Baseline participants made more references to external information during the raid scenario than the attack scenario. This result is not surprising when considering that the goals and objectives identified for non-conventional tactical operations are often more ambiguous and confusing than those identified for conventional operations.

With respect to military relevance, reduced cognitive workload enables commanders to acquire and maintain higher levels of SA (Adams et al., 1995; Wickens, 2008). Reduced cognitive workload also frees the commander to spend his time and resources on higher-level cognitive processes, which may reduce uncertainty and lead to better decisions.

4. Perceived vs. Actual Accuracy

Just prior to the beginning of data collection, researchers decided to ask participants about their perceived accuracy (i.e., 0% = very low, 100% = very high) in their TRACE responses. This decision was based on the researchers' intuition and was intended to provide insights into future research in this area. Although the researchers had no informed hypotheses about what the data would yield, the results proved very interesting.

The results show that RAPTOR users were significantly more accurate in their TRACE answers than Baseline interface users. However, an even more interesting discovery was the significant difference found within the Baseline group. Essentially, Baseline users reported being considerably more accurate in their TRACE answers than they actually were. Perhaps most interesting was the significant group*accuracy interaction. Baseline users perceived themselves to be very accurate, but actually achieved low accuracy. Conversely, RAPTOR users perceived themselves to be less accurate, but actually achieved high accuracy.

Because researchers decided to collect perceived accuracy data late in the study, no research pertaining to confidence or trust in automation was conducted prior to the data being collected and analyzed. Therefore, we were unable to provide concrete explanations for why these results may have occurred.

VI. CONCLUSIONS AND RECOMMENDATIONS

The Conclusions and Recommendations chapter addresses four key areas pertaining to RAPTOR. These comments are applicable to C^2 technologies in general. The key areas are: (1) Study Conclusions; (2) Future Research; (3) Recommendations; and (4) Final Comments. The Study Conclusions section will discuss important information ascertained from the study, while the Future Research section provides a "way-ahead" for RAPTOR's continued development. The Recommendations section focuses on modifications that should be considered for future versions of RAPTOR to help make the interface even more effective for warfighter use. And, the Final Comments section provides the researchers' final thoughts about this study.

A. STUDY CONCLUSIONS

Results from this study indicate that the RAPTOR interface was more effective than the Baseline interface in all areas examined. Six out of seven statistical comparisons between the interfaces were significant, suggesting that performance with the RAPTOR interface was better than performance with the Baseline interface. More importantly, the pattern of results found in this study, coupled with the results found during previous studies, clearly indicate that the theoretical principles used to create RAPTOR provide a very effective interface design strategy for assisting military practitioners in coping with the complexities and uncertainties inherent in C^2. Though no interface will result in complete understanding or perfect SA, RAPTOR has demonstrated its ability to effectively support warfighter cognitive processing while reducing workload, and may also prove to be a significant enabler in assisting the U.S. Army with maintaining a tactical edge over threat forces.

B. FUTURE RESEARCH

This study was bounded within C^2 activities normally conducted during the execution phase of a tactical operation. In reality, effective C^2 begins during the planning and preparation phases, where specific goals are defined and key tasks are determined, and continue through the reconsolidation phase after identified tactical goals and objectives have been achieved. Accordingly, RAPTOR's design concept encompasses a holistic approach toward assisting commanders with C^2 throughout all phases of tactical operations. Thus, the following discussion on future research will focus on three areas of study: (1) additional research on operator trust and confidence when using RAPTOR to assist with C^2; (2) RAPTOR's application to the planning and preparation phases of tactical operations; and (3) RAPTOR's application as an assessment tool.

1. Additional Research on Trust and Confidence

The preliminary perceived and actual accuracy results discussed in Chapters IV and V warrant additional research to provide plausible explanations for why RAPTOR users were less confident, yet more accurate in their TRACE answers, while Baseline users were more confident, yet considerably less accurate in their answers.

As stated previously, prior research pertaining to user confidence and/or trust in automation was not conducted, thus researchers refrained from speculating about why these results may have occurred. However, the results do raise several interesting questions. Perhaps the Baseline users were overconfident given that they all had previous FBCB2 experience in tactical environments. Perhaps RAPTOR users mistrusted the RAPTOR interface given the novelty of, and their inexperience with, the technology. Additional research in this area may provide even more conclusive evidence on RAPTOR's ability to enable warfighters to cope with complex and dynamic situations.

2. Application into Planning and Preparation Phases

This study focused on RAPTOR's ability to enhance warfighter performance during the execution phases of tactical operations. However, the interface is designed to assist with all aspects of C^2; additional research is needed to determine the extent to which RAPTOR enhances the ability of commanders and their staffs to plan and prepare for tactical operations.

Planning is an arduous and time-consuming endeavor that requires activities such as integration, coordination, and synchronization of friendly forces and battlefield operating systems. During this phase, countless hours are dedicated to collecting and calculating (either manually or mentally) detailed estimates to determine the effects that numerous interrelated factors (e.g., friendly capabilities, enemy forces, terrain, weather, time, etc.) will have on tactical operations. Accordingly, RAPTOR is designed to compute many of the same types of data normally calculated by battle staff personnel. Also, RAPTOR's various displays (e.g., friendly combat resource display, enemy combat resource display, force ratio display, and temporal synchronization display) represent data in tables, charts, and graphs that are similar to products typically generated during mission analysis and COA development processes.

Battlefield preparation also requires continuous estimate refinement, COA analysis and comparison, and approval processes. Similar to the planning phase, many of RAPTOR's displays and manipulable tools can assist battle staffs with specific preparation processes. For example, RAPTOR's COA buttons enable the commander and his staff to preview and compare differences between alternative COAs in the spatial synchronization and temporal synchronization modes. The graphical replay slider enables the commander and his staff to preview and analyze pre-planned activities in time and space. RAPTOR can also assist with refining estimates by computing fresh data as updates are received.

Presumably, the speed and efficiency afforded by RAPTOR will enable commanders and staff personnel to spend their time and energy on higher-level processes such as decision making. Thus, studies that examine RAPTOR-aided planning and preparation processes may produce conclusive evidence on the interface's ability to enable battle staffs to receive, process, share, disseminate, and display reliable information faster and more effectively than current C^2 technologies.

3. Application as an Assessment Tool

Commanders must assess actions taken (or not taken) during every phase of a tactical operation to avoid committing similar mistakes during future operations, and to continuously improve overall unit performance. The after-action review (AAR) is a type of assessment routinely conducted during training and in combat. AARs enable commanders to identify deficiencies, sustain proficiency, and focus on strengthening specific task performance. Effective AARs (i.e., those that uncover and capture key lessons learned) explore critical events, actions, and observations by time sequence to prevent the loss of valuable information and to promote constructive feedback (Department of the Army, 1993).

Consequently, assessments such as AARs are another arena in which RAPTOR may be suited to assist commanders. In essence, RAPTOR records graphical representations of events as they transpire in time and space. The plan review mode and graphical replay slider provide commanders with the ability to "rewind" through historical events and locate discrete activities of interest to determine exactly which deviations occurred during precise points in time. In reality, commanders have very limited capabilities to capture activities during combat operations in Afghanistan and Iraq for AAR purposes. Thus, studies that examine RAPTOR-aided AAR processes may illustrate the interface's potential to enable warfighters to ascertain fine details of crucial lessons that may often remain unnoticed during current battlefield operations.

C. RECOMMENDATIONS

The following sections are focused on researchers' observations and participant-elicited feedback that should be considered for future versions of RAPTOR to help make the interface more intuitive and beneficial for warfighter use. Strategies are also described for generalizing RAPTOR's capabilities to other military operations beyond the context of battalion-level command and control.

1. Researcher Observations

a. Display Modifications

Portions of RAPTOR's displays must become more robust in order to represent different structures and capabilities for both friendly and threat forces. The current unit control tree design represents friendly units as an armored task force configuration typically employed by Heavy Brigade Combat Teams (HBCT) before the Army's transformation process began in earnest in 1999. Since then, the Army has fielded Stryker Brigade Combat Teams (SBCT) and reconfigured many HBCTs into Units of Action (UA). The Army also currently fields Infantry Brigade Combat Teams (IBCT), Airborne Brigade Combat Teams (ABCT), and Armored Cavalry Regiments (ACR). Each are uniquely structured and equipped with considerably different capabilities. Furthermore, combat brigades will often receive additional combat multipliers such as attack aviation, field artillery, and military police to enable mission accomplishment. The unit control tree must be sufficiently tailor-able to represent the various force structures and combat multipliers employed by current combat brigade teams.

Similarly, the current enemy combat resource display represents equipment primarily associated with conventional enemy force structures. However, rocket-propelled grenades and improvised explosive devices are the major weapon systems currently used by insurgent forces in Iraq and Afghanistan. Thus, future RAPTOR versions should be sufficiently tailor-able to represent a wide array of capabilities that can be employed by conventional and non-conventional threat forces. Also, force equivalence algorithms must be accurately reflect friendly and enemy force structures to ensure force ratio values are properly computed and presented in the force ratio display.

b. Usability

Currently, information represented by RAPTOR's displays cannot be altered by users. Future versions must include intuitive options and tools that enable users to quickly and efficiently alter, update and refine information represented in the various displays as situations, conditions, and missions change. For example, specific tasks and timing considerations are determined during the mission planning and preparation phases. Staff personnel must be able to populate and refine synchronization points and activities in the spatial and temporal synchronization displays as the plan matures. Staff personnel must also be able to build alternate courses of action, branches, and sequels into the same displays during COA development, comparison, and analysis processes. Furthermore, the unit control tree and enemy resource display must permit staffs to accurately represent force structures as friendly combat elements and multipliers are attached and/or detached, and as threat capabilities change.

An additional capability that should be considered for incorporation into future versions of RAPTOR is a tool that enables staff personnel to build and refine overlays that can be "laid" on top of maps presented in the spatial synchronization display. The Army routinely uses numerous overlays such as graphic control measures, tactical mission graphics, and modified combined obstacle overlays to highlight mission details and directives that require special emphasis (Department of the Army, 2004). RAPTOR should permit users to build, save, access, disseminate, share, and display overlays when required. Users should also have the ability to layer multiple overlays on top of the map, and be able to turn specific overlays "on or off" when needed. FBCB2 enables users to build graphic control measures, but its functionality is very limited in scope. In contrast to FBCB2, the robust overlay capability described is currently supported by FalconView, which is a Windows-based mapping system originally designed for U.S. Air Force aviation mission planning. However, unlike FalconView, RAPTOR should support overlay options representative of symbols and colors that are in accordance with U.S. Army conventions.

2. Participant Feedback

Participants who used the RAPTOR interface during experimental events were asked to complete a brief feedback survey at the conclusion of their final trial. The survey (see Appendix F) consisted of six statements about the different displays, options, and tools presented by the RAPTOR interface. Participants were asked to score how strongly they either agreed or disagreed with each statement by selecting an applicable number on a 5-point Likert scale (1 = strongly disagree and 5 = strongly agree). Participants were also encouraged to provide comments about the specific displays, options, and tools referenced in each statement. The following summarizes participant comments and average scores provided for each statement:

- The individual resource bar chart color codes used in the Friendly Combat Resource Display enables rapid comprehension of unit combat effectiveness (Average Score = 4.5). Three (out of 16) participants stated that certain bar colors were difficult to determine when the chart background color was the same as the bar color. In particular, amber bars tend to appear gray when presented on a chart with an amber background. Additionally, one participant commented that the resource charts would be more effective if all pacing items (e.g., mortar carriers, self-propelled howitzers, etc.) in a unit task organization were added as additional combat parameters.

- The Force Ratio Display facilitates decision making by enabling users to quickly determine which force (friendly or enemy) has a superior advantage (Average score = 4). Five participants stated that the force ratio display is too large, and the value of the data represented does not justify the amount of space dedicated to the display. Two participants commented that the force ratio is great for planning purposes, but during execution, knowing available friendly combat power is more important than knowing force ratio values.
- The Unit Control Tree enables users to quickly determine friendly resource statuses at finer or courser levels of detail (Average score = 4.5). Two participants stated that the unit control tree is a very useful and intuitive tool.
- The COA button assists with decision making by enabling users to rapidly access and view alternative actions friendly forces can execute if required (Average score = 4.375). Three participants stated that the COA review buttons is a great operational tool, but that changes in unit activities between each COA should be highlighted in the temporal synchronization display to better enable users to quickly determine major differences. It is important to note that changes between COAs are highlighted by different color synchronization points and activity lines in the spatial synchronization display. One participant stated that additional buttons

should be added so that branch plans and sequels could also be viewed in the spatial and temporal synchronization displays.

- Information provided in the Temporal Synchronization Display enables users to anticipate future friendly force activities by time, phase, and event (Average score = 4.5). The three participants made the same statements as above about changes in unit activities between each COA should be highlighted for easier recognition.
- The Enemy Combat Resource Chart reduces uncertainty by enabling users to quickly determine enemy strength and combat effectiveness (Average score = 4.25). Three participants stated that the enemy resource display is a very intuitive tool that greatly assists users in determining enemy battle damage assessments and to build an overall mental model of the threat environment.

The below statements stem from the final part of the survey that asked participants to provide general comments about RAPTOR's overall usefulness:

> *RAPTOR is much easier to use than FBCB2. The displays provide comprehensive and visual data representations that facilitate quick and accurate decision making processes.*
>
> *RAPTOR is a great tool that has the potential to streamline many C^2 processes. Data represented by the different displays makes decision making much easier, and the color codes are excellent at enabling rapid battlefield assessments.*
>
> *The only flaw I see with RAPTOR's design is the inability to communicate with people out in the battlespace.*

The statement concerning the force ratio display received the lowest average score and also generated the most comments. The central issues were (1) force ratios are more valuable for decision making during the planning phase and less valuable for decision making during execution phase, and (2) the current display design occupies too much space that could be used to display other types of information. Perhaps future versions of RAPTOR should incorporate a smaller force ratio display. The additional space could be used for branch plan and sequel review buttons as suggested. Human interaction concerns could also be addressed by adding a free text window to enable commanders to "chat" with subordinate commanders. If a smaller force ratio display cannot be designed, perhaps users could be provided with an option to turn the display "on or off" as desired. When turned off, users can access other information recommended by participants. When turned on, the force ratio display would temporarily "mask" the additional information until the force ratio data is no longer required.

3. Progression Strategies

The theoretical constructs used to design RAPTOR may enable the interface to be applied to other military operations beyond the context of battalion level command and control.

a. Application to Higher Level Commands

This study was bounded within C^2 activities occurring at the battalion level. However, battalions normally deploy and conduct tactical operations as a part of larger brigade-size organizations. As stated earlier, many "legacy" brigade combat teams have been restructured into UAs to better fulfill the Army's expeditionary needs. As a result, UA commanders control 3 to 4 maneuver battalions, indirect fire units, engineer assets, and a wide range of intelligence, surveillance, and reconnaissance capabilities (e.g., UAV UGVs, electronic sensor suites, etc.) in order to orchestrate multiple engagements simultaneously. Coordinating and synchronizing various formations and platforms designed to perform distinctive, yet interdependent roles makes C^2 at brigade and higher levels much more complex and dynamic than C^2 activities conducted at battalion levels.

Consequently, the Army is pursuing a Command Post of the Future (CPOF) that enables commanders and staffs to bridge, analyze, and correlate disparate sources of data originating from nodes distributed throughout the battlefield. The goal of CPOF technologies is to aide problem solving and decision making by packaging and presenting data in formats that support human thought processes (DARPA, 2009). Goals established for CPOF could potentially be achieved by implementing RAPTOR's theoretical concepts into the program. RAPTOR's direct perception, manipulation, aggregation, and abstraction hierarchy design principles may prove invaluable at enabling decision-makers to achieve desired levels of information processing, integration, and collaboration throughout all echelons of command.

b. Expansion to Other Military Services

Scenarios used for this study were developed specifically for U.S. Army personnel. However, all military services must cope with the complexities of C^2 during combat operations. Since each service strives to achieve better levels of SA and enhanced decision making, RAPTOR's design principles may also prove useful in assisting U.S Navy carrier group commanders during continuous operations at sea or U.S. Air Force commanders during extended air campaigns. Combat operations executed by the U.S. Marine Corps closely parallel those executed by the U.S. Army. Presumably, RAPTOR's effectiveness at facilitating C^2 activities conducted by U.S. Army personnel may also prove successful for U.S. Marine Corps personnel. Scenarios representative of distinct U.S. Marine Corps tactical problems (e.g., amphibious assault operations) should be developed to explore RAPTOR's applicability into other tactical environments. Future research efforts should consider RAPTOR's impact on the planning and execution of joint military operations.

c. Migration to Civilian Occupations

Effective command and control is not just a military problem. Many civilian businesses routinely plan, synchronize, and coordinate complex activities to reduce risks and ensure best business practices. In particular, the transportation industry (e.g., airlines, railways, trucking companies, etc.) uses sophisticated technologies to plan efficient operator schedules, movement tables, and travel routes to achieve profitable transit goals. Furthermore, finite resource expenditures are a major constraint for transportation planners and operators considering the rising price of gasoline in the current economy. Consequently, transport controllers and asset operators are also becoming more reliant on global positioning systems to track delivery progress and to avoid potential delays caused by weather, traffic, and other types of unforeseen events. However, these technologies are not always capable of producing acceptable solutions given the complex and dynamic environments in which transportation occurs. Operator intervention is often required to solve problems. Although the operating environments are different, the defining characteristics of the objects of interest are similar to those in military C2. Therefore, it is reasonable to speculate that an interface founded on ecological and CSE design principles would provide a very effective strategy for enabling the transportation industry to achieve desired goals and end states.

D. FINAL COMMENTS

Information is vital for success during war. Those who are faster at collecting, analyzing, integrating, and understanding relevant information will gain a superior advantage over any adversary. However, the quest for more information can also degrade operational effectiveness. Research into technologies designed to correctly support human cognition has great potential for enhancing warfighter reasoning and thought processes, while at the same time reducing operator workload. The researchers are confident that the findings in this study will lead to interface designs capable of enhancing military practitioner by improving SA, resulting in better decisions during complex, fluid, and dynamic situations. Additionally, the proposed research areas may also provide conclusive evidence of RAPTOR's potential to facilitate every aspect of C^2 throughout all levels of command and in a wide range of operational environments. Finally, researchers believe results of this study will assist the U.S. Army in its efforts to develop advanced C^2 interfaces that account for human capabilities and limitations.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. ATTACK SCENARIO OPERATIONS ORDER

OPERATION ORDER 08-43 (OPERATION TYPHOON)

References: Map, DMA, 1983, Scale 1:50,000, Series V795, Sheet I

Time Zone Used Throughout Order: Local

Task Organization:

TM A (SF)	TM B (SF)	TM C (SF)
1/A/Tank PLT (4 x M1)	1/B/Tank PLT (4 x M1)	1/C/Mech IN PLT (4 x BFV)
2/A/Tank PLT (4 x M1)	2/B/Tank PLT (4 x M1)	2/C/Mech IN PLT (4 x BFV)
3/C/Mech IN PLT (4 x BFV)	3/B/Tank PLT (4 x M1)	3/A/Tank PLT (4 x M1)
TM D (ME)	TF Mortars	TF Scouts
1/D/Mech IN PLT (4 x BFV)	A/Sec (2 x 120mm)	A/Wheeled Sec (2 x HMMWV)
2/D/Mech IN PLT (4 x BFV)	B/Sec (2 x 120mm)	B/Wheeled Sec (2 x HMMWV)
3/D/Mech IN PLT (4 x BFV)		

1. SITUATION.

a. Battlefield conditions.

(1) Weather. No Change.

(2) Light Data. No Change

(3) Terrain. Elevation gradually increases to the west. The primarily open desert terrain located east of the 47 Easting supports large formations of armored vehicles traveling at high rates of speed.

(4) Obstacles. A large blocking obstacle consisting of anti-tank mines and wire is located to the East of the enemy defensive positions, and runs from North to South across the width of the TF zone. Obstacle belts are tied into the ridges located in the northern and southern portions of the TF zone. The entire length of the blocking obstacle is covered by overlapping direct fires from enemy forces located within OBJ KILLER.

b. Enemy Forces. Immediately opposing our TF are elements of the 269th Motorized Rifle Battalion (MRBN) estimated at 100% strength. The 269th is defending with three Motorized Rifle Companies (MRC) consisting primarily of BMP-2s, and is also believed to be reinforced by one CO of T-72 tanks. Enemy defensive positions have been confirmed at OBJ KILLER. Though no specific combat platforms have been identified, enemy forces projected up to company strength (10-13 vehicles) have been templated on OBJ KILLER.

(1). MLCOA in TF OUTLAW Zone [See Appendix 1 (SITEMP) to Annex B (Intelligence)]. Enemy defends in depth within OBJ KILLER with three BMP PLTs in prepared fighting positions.

(2). MDCOA in TF OUTLAW Zone. Enemy defends in depth vic OBJ KILLER with three BMP PLTs and one T-72 Tank PLT in prepared defenses. Enemy will attempt to flank the TF by conducting a counter-attack into either the southern or northern flanks.

(3). Enemy Composition (Templated).

c. Friendly Situation. The current mission is part of ongoing offensive operations. Due to the OPTEMPO, logistical are experiencing difficulties with resupplying forward units. Thus, TF OUTLAW will execute this mission with severely reduced resources.

2. **MISSION. NLT xxxxJUNxx, TF OUTLAW attacks west toward PL JEFFERSON and destroys enemy forces located vic OBJ KILLER IOT facilitate continued offensive operations by follow-on forces.**

3. EXECUTION.

a. OUTLAW 6 Intent:

Purpose: Complete the destruction of enemy forces in TF LUCKY zone.

Key Tasks:

- Establish multiple breach lanes through enemy obstacle belt.
- Rapid FPOL of TM D to OBJ DALLAS [Decision Point 1 (DP 1)].
- Complete the destruction of enemy forces on OBJ KILLER (TM D).
- Establish screen along PL JEFFERSON.

Endstate:

- Friendly: TF OUTLAW preparing for future combat operations along PL JEFFERSON.
- Enemy: All enemy forces destroyed on OBJ KILLER.

b. Concept of Operations [See Appendix 1 (Concept Sketch) to Annex C (Operations)]. The decisive point of this operation is the rapid FPOL of TM D toward OBJ DALLAS (DP 1) IOT complete the destruction of enemy forces located within OBJ KILLER. This is a 5 phase operation: (1) PL PHOENIX to PL DAMAGE; (2) Breach; (3) Assault OBJ KILLER; (4) FPOL to OBJ DALLAS; (5) Screen. Three courses of action (COA) have been planned based on the first CO/TM to establish a breach lane ***and*** maneuver west of PL RAMPAGE. The following conditions drive which COA will be implemented at DP 1 [See Appendix 3 (Decision Support Matrix) to Annex C (Operations)]:

- COA A (initial COA to be executed) - TM D follows TM B (center zone in AXIS B)toward OBJ KILLER.
- COA B - TM D follows TM C (south zone in AXIS C) toward OBJ KILLER.
- COA C - TM D follows TM A (north zone in AXIS A) toward OBJ KILLER.

c. Scheme of Maneuver [See Appendix 2 (Execution Matrix) to Annex C (Operations)].

(1) PHASE I (PL PHOENIX to PL DAMAGE) – TF Scouts RP PL PHOENIX first, and conduct moving screen along the northern portion of the TF zone IOT protect the TF north flank. Sequentially, once TF Scouts reach PL DAMAGE, TMs A, B, & C RP PL PHOENIX and attack west toward PL DAMAGE. TM A attacks along AXIS A in the north, TM B attacks along AXIS B in the center, and TM C attacks along AXIS C in the south. Once TMs A, B, and C reach PL DAMAGE, TM D departs ATK POS D and TF Mortars depart CP 1 west toward PL PHOENIX. Phase I ends once TF Scouts reach PL RAMPAGE, TMs A, B, and C are arrayed along PL DAMAGE, and TM D with TF Mortars executing PL PHOENIX west toward PL DAMAGE.

(2) PHASE II (BREACH) – (*DP 1 located in this phase*) This phase begins once TMs A, B, and C execute PL DAMAGE west to PL RAMPAGE. TF Scouts establish OP 1 on the key terrain located vic 14RPV 462163 to identify forward edge of enemy obstacles and enemy defensive positions within OBJ KILLER. TF Mortars establish a mortar firing point (MFP) vic CP 2 and prepare to support TF breaching operations with indirect fires. TMs A, B, and C locate enemy obstacles vic PL RAMPAGE and prepare to breach. TF Mortars fire TGT GRP CJ7 to suppress enemy forces on OBJ KILLER. Sequentially, TM D establishes ABF D and destroys enemy forces located vic OBJ KILLER ISO TF breaching operations. TM A breaches in AXIS A, TM B breaches in AXIS B, and TM C breaches in AXIS C. TM D immediately collapses ABF D once the first CO/TM establishes a breach lane and maneuvers west of PL RAMPAGE (***DP 1***). TM D follows the CO/TM toward OBJ KILLER (currently planned as **COA A** behind TM B). TF Scouts remain at OP 1 to observe mortar fires ISO TF breaching operations. Phase II ends with TM D assaulting west through the breach toward OBJ KILLER.

- **Alternate COAs at DP 1 –** In the event TM B does not establish the first breach lane, TF OUTLAW prepares to execute alternate COAs IAW DP 1 criteria.
    - **COA B** is the event TM C establishes the initial breach lane ***and*** maneuvers west of PL RAMPAGE. During COA B, TM D follows TM C south toward OBJ KILLER.
    - **COA C** is the event TM A establishes the initial breach lane ***and*** maneuvers west of PL RAMPAGE. During COA C, TM D follows TM A north toward OBJ KILLER.

(3) PHASE III (ASSAULT OBJ KILLER) – This phase begins once all TMs have maneuvered west of PL RAMPAGE toward OBJ KILLER. TF Mortars fire TGT DF0104 to suppress enemy forces located vic OBJ DALLAS. Simultaneously, TM A assaults OBJ ATLANTA and destroys enemy forces located in the northern portion of OBJ KILLER. TM B assaults OBJ BOSTON and destroys enemy forces located in the forward center portion of OBJ KILLER. TM C assaults OBJ CHICAGO and destroys

enemy forces located in the southern portion of OBJ KILLER. TM D follows and supports TM B on OBJ BOSTON (**COA A**). TF Scouts remain at OP 1 to observe mortar fires ISO TF assault. Phase III ends with enemy forces destroyed in OBJ BOSTON and TM D prepared to conduct FPOL through TM B toward OBJ DALLAS (**COA A**).

- **COA B –** TM D follows and supports TM C on OBJ CHICAGO, and prepares to conduct FPOL through TM C toward OBJ DALLAS.

- **COA C –** TM D follows and supports TM A on OBJ ATLANTA, and prepares to conduct FPOL through TM A toward OBJ DALLAS.

(4) PHASE IV (FPOL to OBJ DALLAS) – This phase begins once conditions have been set to enable TM D to assault remaining enemy forces vic OBJ DALLAS. TM D FPOLs TM B and assaults OBJ DALLAS to complete the destruction of enemy forces within OBJ KILLER (**COA A**). Simultaneously, TF Mortars cease fire on TGT DF0104 once TM D FPOLs TM B. Sequentially, TF Mortars cross the enemy obstacle belt through the lane located in AXIS C and establishes an MFP vic CP 3. TF Scouts remain at OP 1 and provide early warning IOT protect TF north flank. This phase ends once all enemy elements are destroyed vic OBJ KILLER.

- **COA B –**TM D FPOLs TM C and assaults OBJ DALLAS to complete the destruction of enemy forces on OBJ KILLER.

- **COA C –**TM D FPOLs TM A and assaults OBJ DALLAS to complete the destruction of enemy forces on OBJ KILLER.

(5) PHASE V (SCREEN) – This phase begins once all enemy forces are destroyed within OBJ KILLER. TF OUTLAW establishes a screen arrayed along PL JEFFERSON. TM A will establish the screen to the north, TM B establishes the screen in the center, and TM C establishes the screen in the south. TM D consolidates on OBJ DALLAS as the TF reserve. TF Scouts remain at OP 1 and provide early warning IOT

protect TF north flank. TF Mortars remain at CP 3 and prepare to provide indirect fires ISO TF screening operations.

d. Concept of Fires: TF Mortars will remain under TF control for the duration of the operation. The purpose of fires for this operation is to provide suppressive fires on OBJ KILLER. Mortar fires initially support TF breaching operations, then support TM D's assault on OBJ DALLAS.

e. Coordinating Instructions.

- Information Requirements [See Appendix 2 (Commander's Critical Information Requirements) to Annex B (Intelligence)].

- DP Criteria [See Appendix 3 (Decision Support Matrix) to Annex C (Operations)]:
    - First TM to establish breach determines DP 1 criteria. DP 1 is located in Phase II of the operation. DP 1 drives the COA to be executed at the end of Phase II.

4. SERVICE SUPPORT. Current / Projected CO/TM & Specialty PLT level combat resource status [See Appendix 1 (Resource Status Matrix) to Annex I (Logistics).

5. COMMAND and SIGNAL. (No Change)

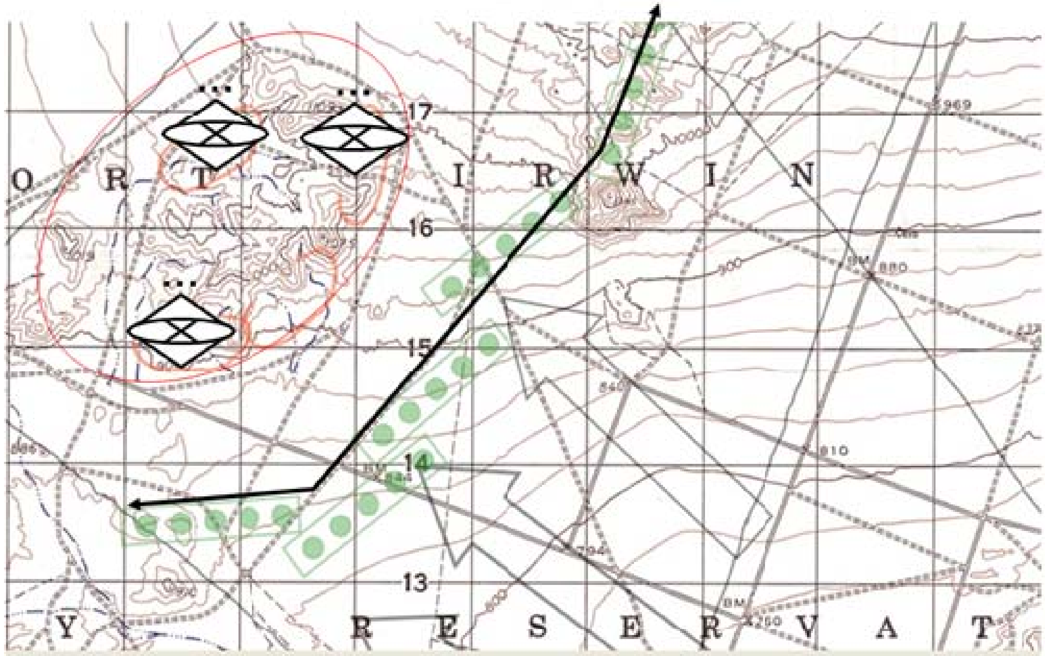
SHATTUCK
LTC

OFFICIAL:
HALL
S3

ANNEXES:
ANNEX B (Intelligence)
APPENDIX 1 (Enemy SITEMP)
APPENDIX 2 (Information Requirements)
ANNEX C (Operations)
APPENDIX 1 (COA Concept Sketches)
APPENDIX 2 (Execution Matrix)
APPENDIX 3 (Decision Support Matrix)
ANNEX I (Logistics)
APPENDIX 1 (Resource Status Matrix)

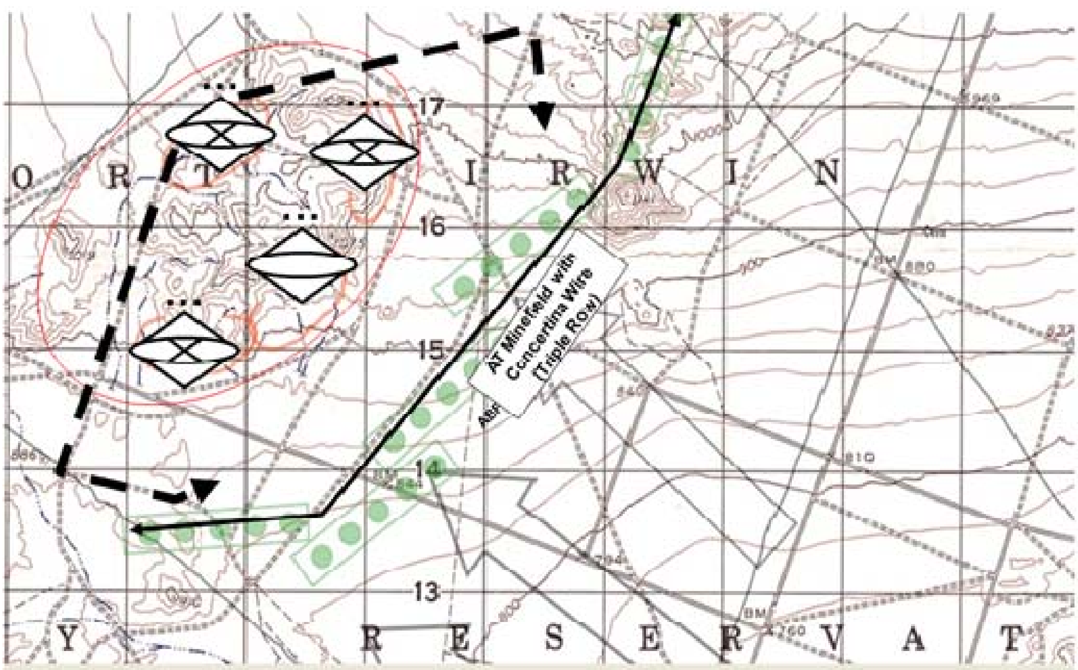
Appendix 1 (SITEMP) to Annex B (Intelligence) to OPORD 08-43 (Operation Typhoon)

MLCOA



Appendix 1 (SITEMP) to Annex B (Intelligence) to OPORD 08-43 (Operation Typhoon)

MDCOA



Appendix 2 (CCIR) to Annex B (Intelligence) to OPORD 08-43 (Operation Typhoon)

Commander's Critical Information Requirements (CCIR)

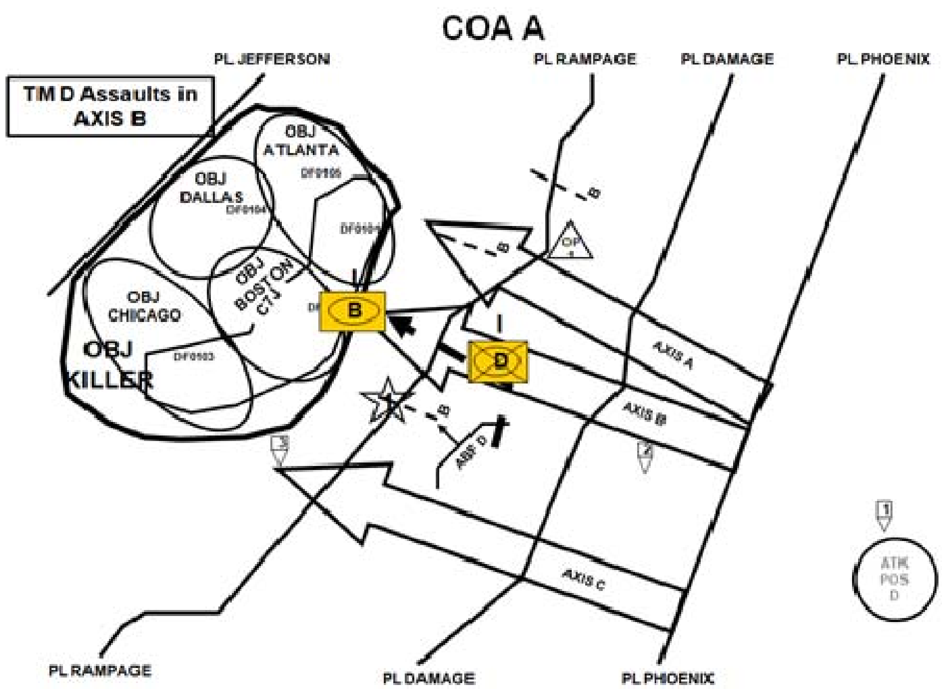
Priority Intelligence Requirements (PIR):

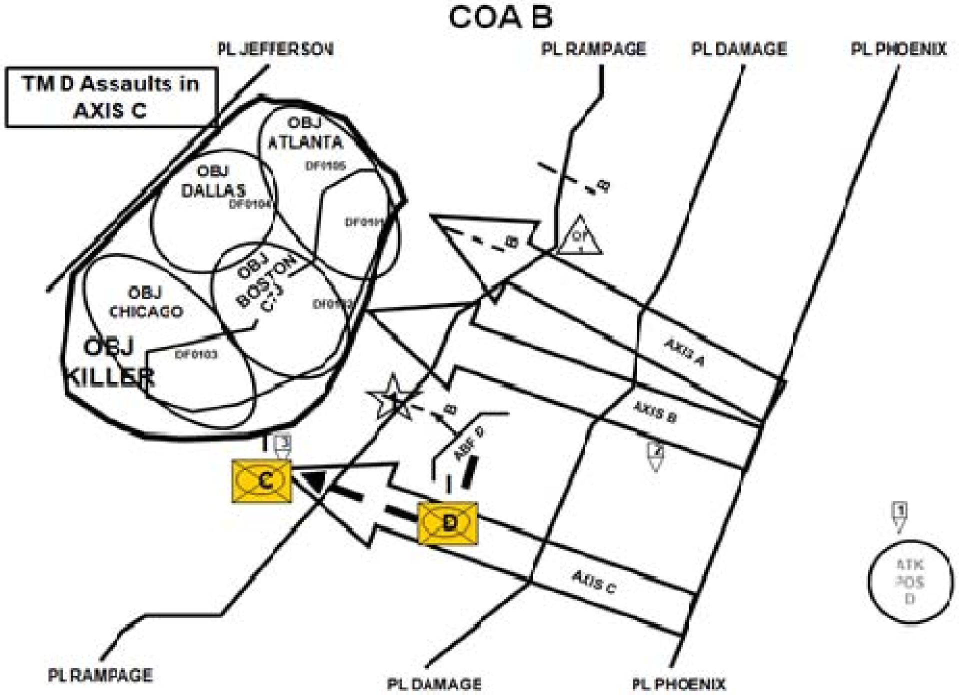
1. Are T-72 tanks present vic OBJ KILLER?
2. What is the enemy's remaining combat power for both T-72s & BMPs (alive + templated) once TM D reaches ABF D?

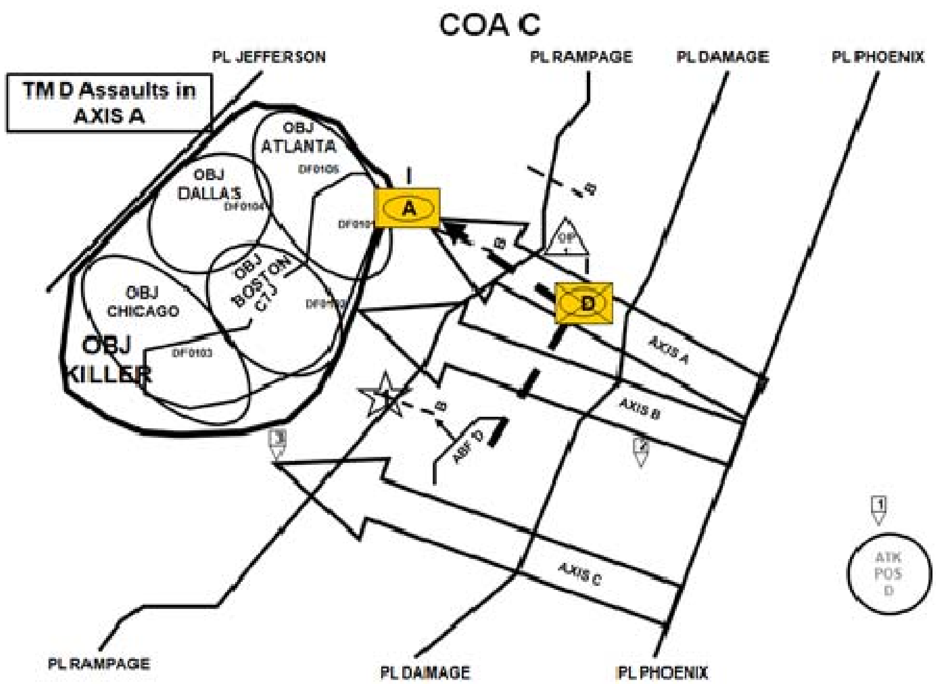
Friendly Force Information Requirements (FFIR):

1. What is the friendly to enemy force ratio (ex. 3:1) once TM D reaches PL DAMAGE?
2. What are the Mortar platoon's resource statuses once they reach PL DAMAGE? (Report color status for ammo, fuel, and vehicles)

Appendix 1 (Concept Sketch) to Annex C (Operations) to OPORD 08-43 (Operation Typhoon)




COA B
PL JEFFERSON
PL RAMPAGE
PL DAMAGE
PL PHOENIX
TM D Assaults in AXIS C
OBJ ATLANTA
OBJ DALLAS
OBJ BOSTON
OBJ CHICAGO
OBJ KILLER
AXIS A
AXIS B
AXIS C
ABF D
C
D
ATK POS D
PL RAMPAGE
PL DAMAGE
PL PHOENIX


COA C
PL JEFFERSON
PL RAMPAGE
PL DAMAGE
PL PHOENIX
TM D Assaults in AXIS A
OBJ ATLANTA
OBJ DALLAS
OBJ BOSTON
OBJ CHICAGO
OBJ KILLER
A
D
AXIS A
AXIS B
AXIS C
ABF D
ATK POS D
PL RAMPAGE
PL DAMAGE
PL PHOENIX

Appendix 2 (Execution Matrix) to Annex C (Operations) to OPORD 08-43 (Operation Typhoon)

COA A

	Phase 1: Phoenix to Damage		Phase 2: Breach		Phase 3: Assault Killer	Phase 4: FPOL to Dallas		
Team A	Hold at Phoenix	Attack to Damage in Axis A	Attack to Rampage	Breach in Axis A	Assault Atlanta	Protect N. Flank	Protect N. Flank	Establish Screen North
Team B	Hold at Phoenix	Attack to Damage in Axis D	Attack to Rampage	Breach in Axis B	Assault Boston	Coordinate FPOL w Tm D	Suppress Dallas	Establish Screen Center N
Team C	Hold at Phoenix	Attack to Damage in Axis C	Attack to Rampage	Breach in Axis C	Assault Chicago	Protect S. Flank	Protect S. Flank	Establish Screen South
Team D	Hold at ATK POS D	Attack to Phoenix	Attack to Damage	Establish ABF D1	Move Thru Lane in Axis B	FPOL TM B	Assault Dallas	Establish Screen Center S
Scouts	Recon To Damage	Recon To Rampage			Call for fire ISO TF			No Change
Mortars	Hold at CP 1	Attack to Phoenix	Est MFP At CP 2	Fire TOT GRP CJ7	Fire TST DFO10H	Move to CP 3	Est MFP At CP 3	Prep to Fire IDF

COA B

	Phase 1: Phoenix to Damage		Phase 2: Breach		Phase 3: Assault Killer	Phase 4: FPOL to Dallas		
Team A	Hold at Phoenix	Attack to Damage in Axis A	Attack to Rampage	Breach in Axis A	Assault Atlanta	Protect N. Flank	Protect N. Flank	Establish Screen North
Team B	Hold at Phoenix	Attack to Damage in Axis D	Attack to Rampage	Breach in Axis B	Assault Boston	Suppress Dallas	Suppress Dallas	Establish Screen Center N
Team C	Hold at Phoenix	Attack to Damage in Axis C	Attack to Rampage	Breach in Axis C	Assault Chicago	Coordinate FPOL w Tm D	Protect S. Flank	Establish Screen South
Team D	Hold at ATK POS D	Attack to Phoenix	Attack to Damage	Establish ABF D1	Move Thru Lane in Axis C	FPOL TM C	Assault Dallas	Establish Screen Center S
Scouts	Recon To Damage	Recon To Rampage			Call for fire ISO TF			No Change
Mortars	Hold at CP 1	Attack to Phoenix	Est MFP At CP 2	Fire TOT GRP CJ7	Fire TST DFO10H	Move to CP 3	Est MFP At CP 3	Prep to Fire IDF

COA C

	Phase 1: Phoenix to Damage		Phase 2: Breach		Phase 3: Assault Killer	Phase 4: FPOL to Dallas		
Team A	Hold at Phoenix	Attack to Damage in Axis A	Attack to Rampage	Breach in Axis A	Assault Atlanta	Coordinate FPOL w Tm D	Protect N. Flank	Establish Screen North
Team B	Hold at Phoenix	Attack to Damage in Axis D	Attack to Rampage	Breach in Axis B	Assault Boston	Suppress Dallas	Suppress Dallas	Establish Screen Center N
Team C	Hold at Phoenix	Attack to Damage in Axis C	Attack to Rampage	Breach in Axis C	Assault Chicago	Protect S. Flank	Protect S. Flank	Establish Screen South
Team D	Hold at ATK POS D	Attack to Phoenix	Attack to Damage	Establish ABF D1	Move Thru Lane in Axis A	FPOL TM A	Assault Dallas	Establish Screen Center S
Scouts	Recon To Damage	Recon To Rampage			Call for fire ISO TF			No Change
Mortars	Hold at CP 1	Attack to Phoenix	Est MFP At CP 2	Fire TOT GRP CJ7	Fire TST DFO10H	Move to CP 3	Est MFP At CP 3	Prep to Fire IDF

Appendix 3 (Decision Support Matrix) to Annex C (Operations) to OPORD 08-43 (Operation Typhoon)

Decision Point 1 Criteria (PL RAMPAGE)

COA	Enemy Conditions	Friendly Conditions	Friendly Action	Location
A	Initial breach thru enemy obstacles occurs in Axis B	TM B west of PL RAMPAGE	TM D assaults toward OBJ KILLER in AXIS B **(Center Zone)**	Axis B
B	Initial breach thru enemy obstacles occurs in Axis C	TM C west of PL RAMPAGE	TM D assaults toward OBJ KILLER in AXIS C **(South Zone)**	Axis C
C	Initial breach thru enemy obstacles occurs in Axis A	TM A west of PL RAMPAGE	TM D assaults toward OBJ KILLER in AXIS A **(North Zone)**	Axis A

Appendix 1 (Resource Status Matrix) to Annex I (Logistics) to OPORD 08-43 (Operation Typhoon)

Task Force Level Resource Status				Company Level Resource Status			Platoon Level Resource Status	
COMBAT RESOURCES		OVERALL STATUS		UNIT	OVERALL STATUS		PLT	OVERALL STATUS
Type	Initial Values	Initial	Projected		Initial	Projected		Initial
Fuel	12, 620 Gal	AMBER	BLACK	TM A	AMBER	BLACK	1st PLT (Tank)	AMBER
							2nd PLT (Tank)	AMBER
							3rd PLT (BFV)	RED
Ammo	16, 244 (T/T + 25)	AMBER	BLACK	TM B	AMBER	BLACK	1st PLT (Tank)	AMBER
							2nd PLT (Tank)	AMBER
							3rd PLT (Tank)	AMBER
BFV	24	GREEN	BLACK	TM C	AMBER	BLACK	1st PLT (BFV)	RED
							2nd PLT (BFV)	RED
							3rd PLT (Tank)	AMBER
Tank	24	GREEN	BLACK	TM D	RED	BLACK	1st PLT (BFV)	RED
							2nd PLT (BFV)	RED
							3rd PLT (BFV)	RED
							TF Mortars	RED
							TF Scouts	GREEN

Authorized Unit Basic Load for Resupply Operations:

TF Resource UBL (100%)	
Type	QTY
T/T	1248
25	21600
Fuel (Gal)	14676
BFV	24
Tank	24

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. RAID SCENARIO OPERATIONS ORDER

OPERATION ORDER 08-44 (OPERATION WHIPLASH)

References: Map, Falcon View version 6, 1998, Al Icia Maria, Isconderia, Special

Time Zone Used Throughout Order: Local

Task Organization:

TM A (SE)	TM B (SE)	TM C (SE)
1/A/Tank PLT (4 x M1)	1/B/Tank PLT (4 x M1)	1/C/Mech IN PLT (4 x BFV)
2/A/Tank PLT (4 x M1)	2/B/Tank PLT (4 x M1)	2/C/Mech IN PLT (4 x BFV)
3/C/Mech IN PLT (4 x BFV)	3/B/Tank PLT (4 x M1)	3/A/Tank PLT (4 x M1)
TM D (ME)	TF Mortars	TF Scouts
1/D/Mech IN PLT (4 x BFV)	A/Sec (2 x 120mm)	A/Wheeled Sec (2 x HMMWV)
2/D/Mech IN PLT (4 x BFV)	B/Sec (2 x 120mm)	B/Wheeled Sec (2 x HMMWV)
3/D/Mech IN PLT (4 x BFV)		

1. SITUATION.

a. Battlefield conditions.

(1) Weather. No Change.

(2) Light Data. No Change.

(3) Terrain. AL ICIA MARIA is complex urban terrain severely restricts friendly vehicular movement. Most roads facilitating armor vehicles only enable west-east travel in column formations. Narrow roads surrounded by structures create numerous choke points and kill zones.

(4) Obstacles. Enemy is anticipated to employ IEDs within choke points and street intersections.

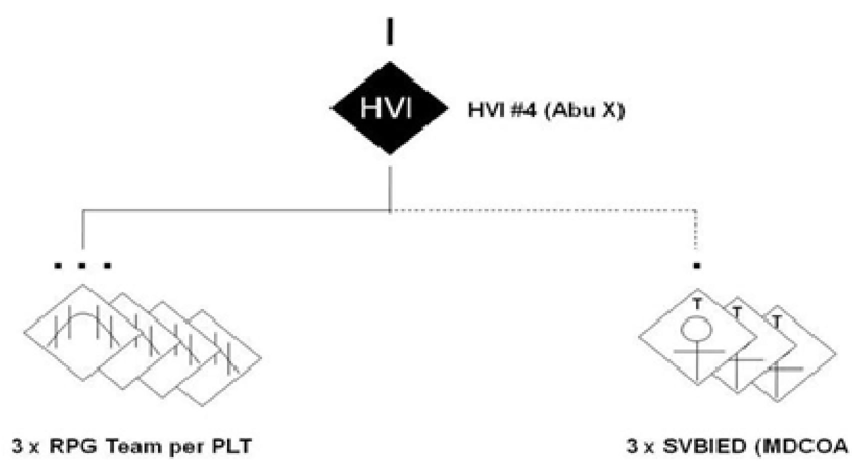
b. Enemy Forces. AL ICIA MARIA is located three kilometers west of the SCIRIAN border, and has become a major point of infiltration for foreign supplied weapons, fighters, and money being funneled to the Anti-Isconderian Forces (AIF). HUMINT sources suggest that ABU X is directly overseeing all AIF activities in and around AL ICIA MARIA. ABU X is currently listed as Number 4 on the Coalition Force

(CF) High Value Individual (HVI) target list. HUMINT sources revealed that ABU X has been routinely traveling from SCIRIA to AL ICIA MARIA in a black two door Opal for the past couple of months. HUMINT sources also revealed that ABU X often conducts meetings from safe houses located vic OBJs DYLAN and BRUCE. Recent SIGINT indicates that ABU X is currently located within AL ICIA MARIA and plans to meet with other insurgent leaders. Additionally, Isconderian Security Forces (ISF) report that the AIF is using a school located vic OBJ CRAZY as an insurgent recruiting station. The AIF is also believed to have established an improvised explosive device (IED) and vehicle-borne improvised explosive device (VBIED) factory vic OBJ ADAM. Intelligence sources currently estimate 20-30 AIF personnel operating within AL ICIA MARIA.

(1). MLCOA in TF OUTLAW AOR [See Appendix 1 (SITEMP) to Annex B (Intelligence)]. ABU X will depart AL ICIA MARIA in anticipation of CF operations. Hard core fighters will conduct attacks consisting of IEDs, anti-armor ambush teams with multiple RPGs, and limited mortar fires to discourage CF from entering into key AIF areas of operation.

(2). MDCOA in TF OUTLAW AOR. AIF employs VBIEDs to enable ABU X to exfiltrate east toward SCIRIA.

(3). Enemy Composition (Templated).



c. Friendly Situation. The current mission is part of ongoing offensive operations. Due to the OPTEMPO, logistical are experiencing difficulties with resupplying forward units. Thus, TF OUTLAW will execute this mission with severely reduced resources.

2. **MISSION. NLT xxxxJUNxx, TF OUTLAW raids insurgent support zones in AL ICIA MARIA IOT disrupt AIF operations within AO OUTLAW.**

3. EXECUTION.

a. OUTLAW 6 Intent:

Purpose: Disrupt AIF activities within AL ICIA MARIA.
Key Tasks:

- Conduct precision raids against specified objectives within AL ICIA MARIA.
- Capture/Kill HVI # 4.
- Destroy insurgent safe havens, training facilities, and munitions factory.

Endstate:

- Friendly: TF OUTLAW preparing for future COIN operations in AOR OUTLAW.
- Enemy: Insurgent Groups neutralized and unable to support ongoing AIF activities.

b. Concept of operations [See Appendix 1 (Concept Sketch) to Annex C (Operations)]. The decisive point of this operation is the capturing/killing of HVI # 4 through rapid and violent execution. This is a 4 phase operation: (1) Initial assault; (2), raids; (3) complete AIF destruction; (4) exfiltration. Three courses of action (COA) have been planned based on HVI # 4's location. These conditions will drive which COA is implemented at DP 1 [See Appendix 3 (Decision Support Matrix) to Annex C (Operations)]:

- **COA A** (initial COA to be executed) - HVI # 4 located vic OBJ DYLAN. TM D executes raid on OBJ DYLAN and captures/kills HVI # 4.
- **COA B** - HVI # 4 **not** identified within AL ICIA MARIA. TM C executes raid on OBJ BRUCE.
- **COA C** - HVI # 4 located vic OBJ BRUCE. TM A executes raid on OBJ BRUCE.

c. Scheme of Maneuver [See Appendix 2 (Execution Matrix) to Annex C (Operations)].

(1) PHASE I (INITIAL ASSAULT) – This phase begins with TF Scouts at OP 1 to gain observation on OBJs DYLAN and BRUCE. Simultaneously, TM C establishes SBF C1, and TF Mortars establish MFP vic CP 1 to enable TF freedom of maneuver during the initial assault into the town. Sequentially, TMs A & D attack toward PL TIGRIS along RTEs AGGIES and DYNAMITE respectively. TM B establishes ATK POS B and prepares to attack along RTE BONFIRE. TF Mortars fire TGT GRP CJ7 once TM D executes PL RHINE to suppress possible anti-armor ambush teams operating in the northern forest. TM C departs SBF C1 and attacks along RTE CROW to PL AMAZON once TM A executes PL AMAZON. Simultaneously, TM B departs ATK POS B and clears RTE BONFIRE east from PL RHINE to PL AMAZON once TMs A & D execute PL AMAZON. This phase ends with TF OUTLAW maneuvering toward specified OBJs.

(2) PHASE II (RAIDS) – This phase begins with TM A executing a raid on OBJ ADAM to destroy enemy IED/VBIED factory, while TM B clears RTE BONFIRE from PL AMAZON to PL TIGRIS. Sequentially, TF Mortars fire TGT DF0104 once TM D executes PL TIGRIS to deny enemy exfiltration east from OBJ DYLAN. Once TM A seizes OBJ ADAM, TM C raids OBJ CRAZY to destroy AIF recruiting center, while TM D raids OBJ DYLAN to capture/kill HVI # 4 (**COA A**). TF Scouts remain at OP 1 and continue to observe assigned areas of observation. This phase ends with TMs A, C, & D completing raids on their assigned OBJs, and with TM B clearing RTE BONFIRE east to PL TIGRIS.

(3) PHASE III (COMPLETE AIF DESTRUCTION) – (*DP 1 located in this phase*) This phase begins with TM A establishing SBF A1 to suppress enemy elements located vic OBJ BRUCE. Sequentially, once TM A establishes SBF A1, TMs C & D complete actions on their OBJs and establish SBFs C2 & D1 respectively to

suppress enemy elements vic OBJ BRUCE. TF Mortars fire TGT DF0105 once TM D establishes SBF D1 to suppress enemy elements on OBJ BRUCE. Once all SBFs are established, TM B executes PL TIGRIS and attacks toward OBJ BRUCE. TF Mortars cease fires on TGT DF0105 once TM B executes PL NILE. Sequentially, TM B raids OBJ BRUCE and completes the disruption of AIF activities within AL ICIA MARIA (**COA A**). TF Scouts remain at OP 1 and continue to observe assigned areas of observation. This phase ends with all raids complete and HVI # 4 captured, killed, or confirmed not present within AL ICIA MARIA.

- **Alternate COAs at DP 1** - In the event HVI # 4 is not located vic OBJ DYLAN, TF OUTLAW prepares to execute alternate COAs IAW DP 1 criteria.

    - **COA B** is in the event HVI #4's location **cannot** be identified within AL ICIA MARIA. During COA B, TM C bypasses SBF C2 and raids OBJ BRUCE to complete the disruption of AIF activities within AL ICIA MARIA. TM B executes PL TIGRIS and establishes SBF C2. TMs A & D remain at SBFs A1 & D1 respectively, and continue to suppress OBJ BRUCE ISO TM C. TF Mortars cease TGT DF0105 once TM C reaches SBF C2.

    - **COA C** is executed if HVI # 4 is located in the vicinity of OBJ BRUCE. During COA C, TM A immediately departs/bypasses SBF A1 and attacks toward OBJ BRUCE to capture/kill HVI # 4 IOT deny his escape from the battlespace. TMs C & D remain at SBFs C2 & D1 respectively, and continue to suppress OBJ BRUCE ISO TM A. TM B holds at PL TIGRIS along RTE BONFIRE. TF Mortars cease fire on TGT DF0105 once TM A departs SBF A1.

(4) PHASE IV (EXFILTRATION) – This phase begins on order (O/O) once all OBJs have been thoroughly searched and all detainees have been secured.

d. Concept of Fires: TF Mortars will remain under TF control for the duration of the operation. The purpose of fires for this operation is to enable the TF to maintain freedom of maneuver during the duration of the operation by providing suppressive fires on pre-designated targets. Mortar fires initially support TM D as they maneuver along RTE DYNAMITE, then during TM D's raid on OBJ DYLAN. Mortar fires sequentially support the raid on OBJ BRUCE.

e. Coordinating Instructions.

- Information Requirements [See Appendix 2 (Commander's Critical Information Requirements) to Annex B (Intelligence)].

    - DP Criteria [See Appendix 3 (Decision Support Matrix) to Annex C (Operations)]:
        - HVI # 4's location determines DP 1 criteria. DP 1 is located in the beginning of Phase III of the operation. DP 1 drives the COA to be executed during Phase III.

4. SERVICE SUPPORT. Current / Projected CO/TM & Specialty PLT level combat resource status [See Appendix 1 (Resource Status Matrix) to Annex I (Logistics).

5. COMMAND and SIGNAL. (No Change)

SHATTUCK
LTC

OFFICIAL:
HALL
S3

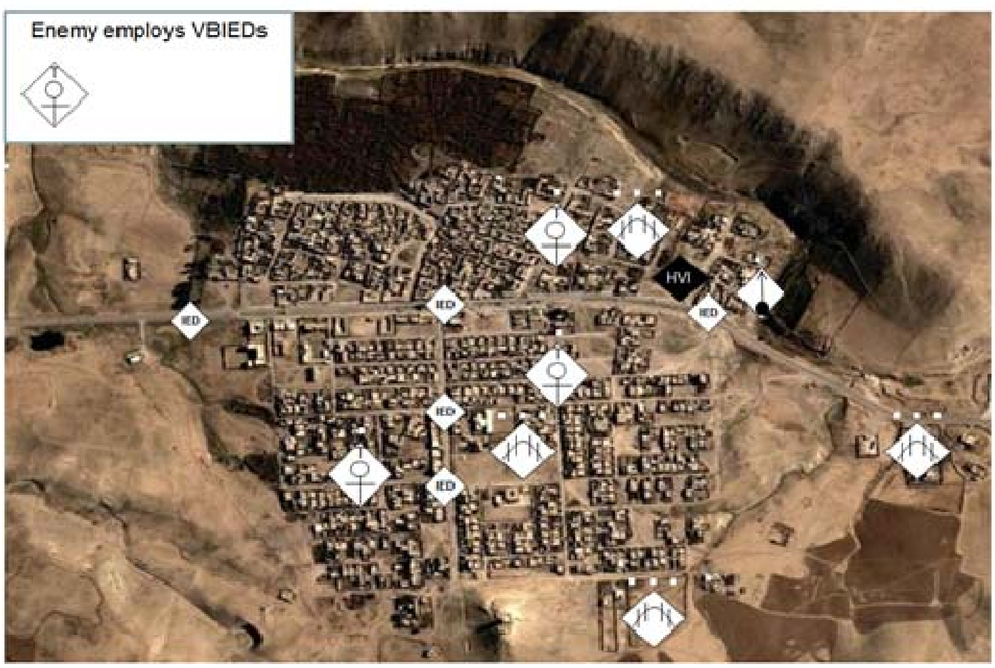
ANNEXES:
ANNEX B (Intelligence)
APPENDIX 1 (Enemy SITEMP)
APPENDIX 2 (Information Requirements)
ANNEX C (Operations)
APPENDIX 1 (COA Concept Sketches)
APPENDIX 2 (Execution Matrix)
APPENDIX 3 (Decision Support Matrix)
ANNEX I (Logistics)
APPENDIX 1 (Resource Status Matrix)

Appendix 1 (SITEMP) to Annex B (Intelligence) to OPORD 08-44 (Operation Whiplash)

MLCOA

Appendix 1 (SITEMP) to Annex B (Intelligence) to OPORD 08-44 (Operation Whiplash)

MDCOA



Appendix 2 (CCIR) to Annex B (Intelligence) to OPORD 08-44 (Operation Whiplash)

Commander’s Critical Information Requirements (CCIR)

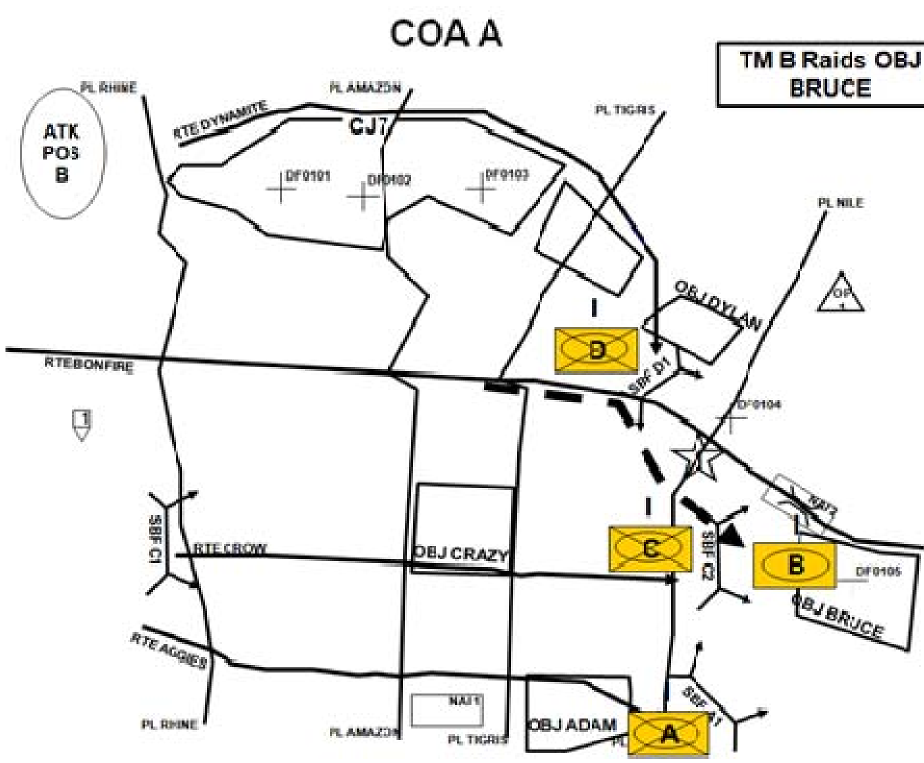
Priority Intelligence Requirements (PIR):

3. Is the enemy employing VBIEDs within AL ICIA MARIA?
4. What is the enemy’s remaining combat power for both RPG Teams and VBIEDs (alive + templated) once TM C reaches PL TIGRIS?

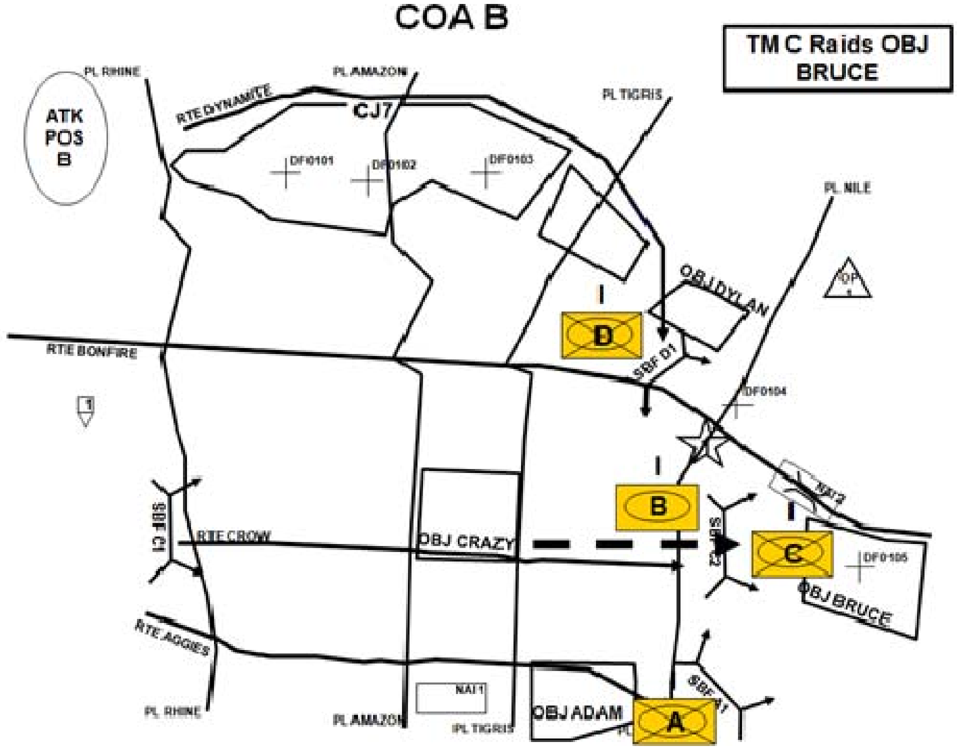
Friendly Force Information Requirements (FFIR):

3. What are TM A’s resource statuses once they reach PL AMAZON? (Report color status for ammo, fuel, and vehicles)
4. What is the friendly to enemy force ratio (ex. 3:1) once TM B reaches PL AMAZON?

Appendix 1 (Concept Sketch) to Annex C (Operations) to OPORD 08-44 (Operation Whiplash)

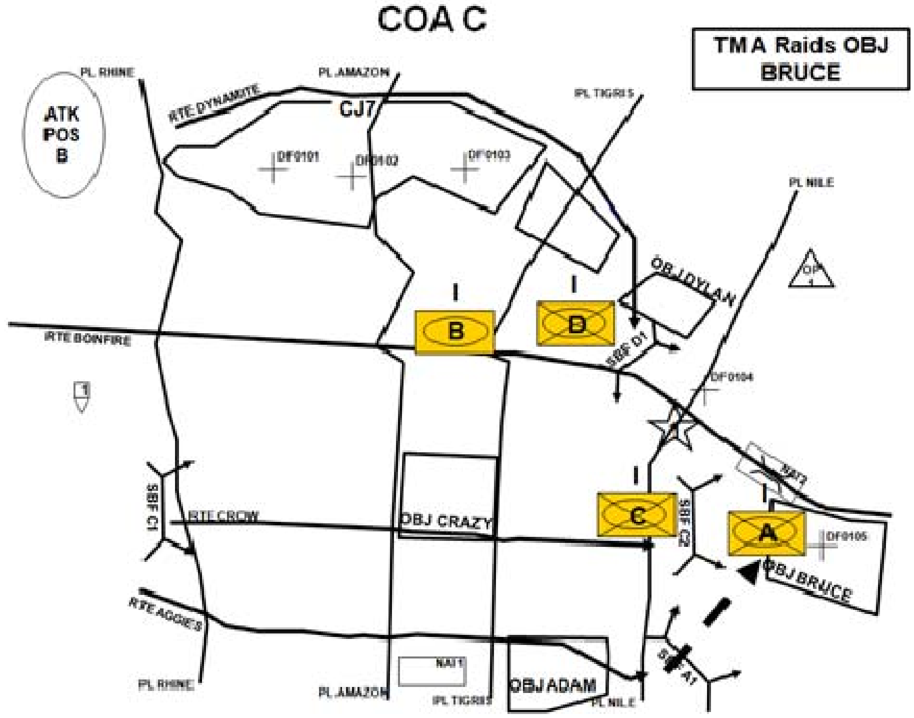


COA B



TM C Raids OBJ BRUCE
ATK POS B
PL RHINE
PL AMAZON
PL TIGRIS
PL NILE
RTE DYNAMITE
CJ7
DF0101
DF0102
DF0103
DF0104
DF0105
OBJ DYLAN
OP
RTE BONFIRE
SBF D1
D
B
C
A
SBF C1
RTE CROW
OBJ CRAZY
SBF C2
NAI 2
OBJ BRUCE
RTE AGGIES
SBF A1
NAI 1
OBJ ADAM

COA C



TM A Raids OBJ BRUCE
ATK POS B
PL RHINE
PL AMAZON
PL TIGRIS
PL NILE
RTE DYNAMITE
CJ7
DF0101
DF0102
DF0103
DF0104
DF0105
OBJ DYLAN
OP
RTE BONFIRE
SBF D1
B
D
C
A
SBF C1
RTE CROW
OBJ CRAZY
SBF C2
NAI 2
OBJ BRUCE
RTE AGGIES
SBF A1
NAI 1
OBJ ADAM

Appendix 2 (Execution Matrix) to Annex C (Operations) to OPORD 08-44 (Operation Whiplash)

COA A

	Phase 1: Initial Assault			Phase 2: Raids		Phase 3: Complete AIF Destruction	
Team A	Attack to Aggies	Attack to Amazon along Aggies	Attack to Tigris along Aggies	Raid OBJ Adam	Est SBF A1	Suppress OBJ Bruce	Suppress OBJ Bruce
Team B	Establish ATK POS B	Hold at ATK POS B	Attack to Rhine along Bonfire	Clear Bonfire To Amazon	Clear Bonfire To Tigris	Clear Bonfire To Nile	Raid OBJ Bruce
Team C	Est SBF C1	Suppress from SBF C1	Attack along Crow	Attack to Amazon along Crow	Raid OBJ Crazy	Est SBF C2	Suppress OBJ Bruce
Team D	Attack to Dynamite	Attack to Amazon Along Dynamite	Attack to Tigris along Dynamite	Prepare to Raid Dylan	Raid OBJ Dylan	Est SBF D1	Suppress ObjBruce
Scouts			Observe RTE BONFIRE and OBJs Bruce & Dylan from OP #; Call for Fire ISO TF				
Mortars	Est MFP at CP 1	Fire TOT GRP CJ7		BPT Fire DF ISO TF	Fire TOT DF0104	Fire TOT DF0105	BPT Fire IDF ISO TF

COA B

	Phase 1: Initial Assault			Phase 2: Raids		Phase 3: Complete AIF Destruction	
Team A	Attack to Aggies	Attack to Amazon along Aggies	Attack to Tigris along Aggies	Raid OBJ Adam	Est SBF A1	Suppress OBJ Bruce	Suppress OBJ Bruce
Team B	Establish ATK POS B	Hold at ATK POS B	Attack to Rhine along Bonfire	Clear Bonfire To Amazon	Clear Bonfire To Tigris	Execute Tigris To SBF C2	Est SBF C2
Team C	Est SBF C1	Suppress from SBF C1	Attack along Crow	Attack to Amazon along Crow	Raid OBJ Crazy	Prepare to Raid Bruce	Raid OBJ Bruce
Team D	Attack to Dynamite	Attack to Amazon Along Dynamite	Attack to Tigris along Dynamite	Prepare to Raid Dylan	Raid OBJ Dylan	Est SBF D1	Suppress ObjBruce
Scouts			Observe RTE BONFIRE and OBJs Bruce & Dylan from OP #; Call for Fire ISO TF				
Mortars	Est MFP at CP 1	Fire TOT GRP CJ7		BPT Fire DF ISO TF	Fire TOT DF0104	Fire TOT DF0105	BPT Fire IDF ISO TF

COA C

	Phase 1: Initial Assault			Phase 2: Raids		Phase 3: Complete AIF Destruction	
Team A	Attack to Aggies	Attack to Amazon along Aggies	Attack to Tigris along Aggies	Raid OBJ Adam	Est SBF A1	Prepare to Raid Bruce	Raid OBJ Bruce
Team B	Establish ATK POS B	Hold at ATK POS B	Attack to Rhine along Bonfire	Clear Bonfire To Amazon	Clear Bonfire To Tigris	Hold at Tigris	Hold at Tigris
Team C	Est SBF C1	Suppress from SBF C1	Attack along Crow	Attack to Amazon along Crow	Raid OBJ Crazy	Est SBF C2	Suppress OBJ Bruce
Team D	Attack to Dynamite	Attack to Amazon Along Dynamite	Attack to Tigris along Dynamite	Prepare to Raid Dylan	Raid OBJ Dylan	Est SBF D1	Suppress ObjBruce
Scouts			Observe RTE BONFIRE and OBJs Bruce & Dylan from OP #; Call for Fire ISO TF				
Mortars	Est MFP at CP 1	Fire TOT GRP CJ7		BPT Fire DF ISO TF	Fire TOT DF0104	Fire TOT DF0105	BPT Fire IDF ISO TF

Appendix 3 (Decision Support Matrix) to Annex C (Operations) to OPORD 08-44 (Operation Whiplash)

Decision Point 1 Criteria (PL NILE)

COA	Enemy Conditions	Friendly Conditions	Friendly Action	Location
A	HVI # 4 location confirmed at OBJ DYLAN	TM D maneuvering to establish SBF D1 TM C manuevering to establish SBF C2 TM A at SBF A1	TM B raids OBJ BRUCE	OBJ BRUCE
B	HVI # 4 not located within AL ICIA MARIA	TM D maneuvering to establish SBF D1 TM B maneuvering to establish SBF C2 TM A at SBF A1	TM C raids OBJ BRUCE	OBJ BRUCE
C	HVI # 4 located vic OBJ BRUCE	TM D maneuvering to establish SBF D1 TM C manuevering to establish SBF C2 TM B holds at PL TIGRIS	TM A raids OBJ BRUCE	OBJ BRUCE

Appendix 1 (Resource Status Matrix) to Annex I (Logistics) to OPORD 08-44 (Operation Whiplash)

Task Force Level Resource Status				Company Level Resource Status			Platoon Level Resource Status	
COMBAT RESOURCES		OVERALL STATUS		UNIT	OVERALL STATUS		PLT	OVERALL STATUS
Type	Initial Values	Initial	Projected		Initial	Projected		Initial
Fuel	12, 620 Gal	AMBER	BLACK	TM A	AMBER	BLACK	1st PLT (Tank)	AMBER
							2nd PLT (Tank)	AMBER
							3rd PLT (BFV)	RED
Ammo	16, 244 (T/T + 25)	AMBER	BLACK	TM B	AMBER	BLACK	1st PLT (Tank)	AMBER
							2nd PLT (Tank)	AMBER
							3rd PLT (Tank)	AMBER
BFV	24	GREEN	BLACK	TM C	AMBER	BLACK	1st PLT (BFV)	RED
							2nd PLT (BFV)	RED
							3rd PLT (Tank)	AMBER
Tank	24	GREEN	BLACK	TM D	RED	BLACK	1st PLT (BFV)	RED
							2nd PLT (BFV)	RED
							3rd PLT (BFV)	RED
							TF Mortars	RED
							TF Scouts	GREEN

Authorized Unit Basic Load for Resupply Operations:

TF Resource UBL (100%)	
Type	QTY
T/T	1248
25	21600
Fuel (Gal)	14676
BFV	24
Tank	24

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. PARTICIPANT DEMOGRAPHIC SURVEY

1. Age: ________

2. Gender: M F

3. Rank / Grade: ________

4. Career Branch (Ex. Armor): ________

5. Years of Service: ________
(Round to nearest year)

6. Are you color blind? Y N

7. Do you have command experience? Y N

If Yes, total command time: ________ (months)

8. Have you ever been assigned as a Battle Captain? Y N

If Yes, total Battle Captain time: ________ (months)

9. Have you ever been assigned as either of the following? (mark all that apply)

______ S-3 No. of months: ______

______ Assist S – 3 No. of months: ______

10. Do you have combat experience? Y N

If Yes,
Number of Combat Deployments: ______

Total Combat Time: ______ (months)

11. Do you have any operations other than war (MOOTW) deployment experience? Y N

Number of MOOTW deployments: ______

Total MOOTW Deployment Time ______ (months)

12. Do you have any Combat Training Center (CTC) rotation experience as a player? Y N

If Yes,
Total number of CTC player rotations: ______

13. Do you have experience using FBCB2 or BFT? Y N

If Yes, type of FBCB2 experience? (mark all that apply)

______ Trainee

______ Trainer

______ Operational

14. Have you ever been assigned as a "Puckster" during a simulated combat exercise? Y N

If Yes,
Assigned role as a Puckster: ______ (Ex. Co Cdr)

15. Do you play interactive video games on a computer or some other gaming system? Y N

If Yes,
Average hours per week spent gaming: ______

16. Rate your confidence level in using a computer between 1 (very low) to 5 (very high): ______

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D. RAPTOR POST-TRAINING TEST

Directions: The following questions pertain to specific functions, tools, options, displays, and representations presented by the RAPTOR interface. The purpose of this questionnaire is to ensure proper levels of knowledge required for the successful operation of the interface are achieved prior to the conduct of the experimental trials. Please read each question carefully, then circle the letter that corresponds to the correct answer.

1. Alternate courses of action (COA) can be previewed by:

   A. Clicking and dragging synchronization points in the map display

   B. Clicking and dragging synchronization points in the synchronization matrix

   C. Placing the cursor over a desired COA button located under the synchronization matrix

   D. All of the above

2. BN level resource color statuses can be determined by:

   A. Requesting a SITREP from subordinate units

   B. Referencing the individual resource bars located in BN level resource chart

   C. Both A & B

   D. None the above

3. PLT level resource color statuses can be determined by:

   A. Selecting a desired PLT bubble in the Unit Control Tree, then referencing the individual resource bars located in PLT level resource chart

   B. Requesting a SITREP from subordinate units

   C. PLT level resources statuses cannot be determined

   D. None of the above

4. Alternate COAs can be executed by:

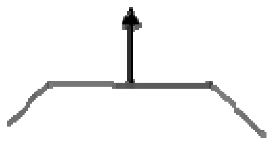
   A. Pointing and clicking on a desired COA button, then pointing and clicking on the current COA selection button

   B. Clicking, dragging, and releasing icons in the map display

   C. Clicking and dragging the control slider located above the synchronization matrix

D. All of the above

5. The following graphic control measure represents:



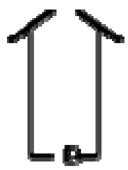
A. Support by fire

B. Attack by fire

C. Breach

D. None of the above

6. The following graphic control measure represents:



A. Breach

B. Direction of attack

C. Blocking position

D. None of the above

7. The following graphic control measure represents:

A. Attack by fire

B. Breach

C. Support by fire

D. None of the above

8. The following graphic control measure represents:

A. Coordination point

B. Decision Point

C. Check point

D. None of the above

9. The enemy resource chart provides information for:

A. Quantities of identified (alive/known) enemy equipment

B. Quantities of destroyed enemy equipment

C. Quantities of templated (anticipated) enemy equipment

D. All of the above

10. Follow-on / next tasks to be executed by subordinate units can be anticipated by referencing text cells to the right of those cells currently intersected by the blue timeline in the synchronization matrix

True / False (Circle One)

11. Current force ratios can be determined by:

A. Calculating the number of remaining enemy and friendly vehicles

B. Referencing where the reflecting line intersects the right edge of a display grid in the force ratio display

C. Force ratios cannot be determined

D. None of the above

12. The below icons represent:

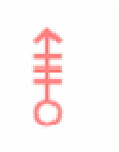
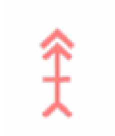
A. Mortar System / Howitzer

B. Tank / Infantry Fighting Vehicle

C. Anti-Tank Rocket Launcher / Building

D. None of the above

13. The below icons represent:

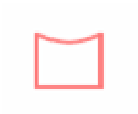
A. Mortar System / Anti-Tank Rocket Launcher (RPG)

B. Howitzer / Anti-Aircraft Gun

C. Tank / HMMWV

D. None of the above

14. The below icon with a ***red** diamond background* represents:



A. Unknown Wheeled Vehicle

B. Infantry Fighting Vehicle

C. VBIED

D. None of the above

APPENDIX E. BASELINE POST-TRAINING TEST

Directions: The following questions pertain to specific functions, tools, options, menus, and representations presented by the Baseline interface. The purpose of this questionnaire is to ensure proper levels of knowledge required for the successful operation of the interface are achieved prior to the conduct of the experimental trials. Please read each question carefully, then circle the letter that corresponds to the correct answer.

1. Reports can be accessed by:
   A. Selecting the Applications button
   B. Selecting the CMD Directives button
   C. Selecting the FIPR button
   D. All of the above
2. Types and quantities of ***destroyed*** enemy vehicles can be determined by:
   A. Accessing SPOT reports in the FIPR menu
   B. Requesting a SITREP from subordinate units
   C. Accessing enemy battle damage assessment reports (E-BDA) in the FIPR menu
   D. None of the above
3. Subordinate unit resource statuses (e.g., fuel, ammunition, etc.) can be determined by:
   A. Referencing unit icon color codes in the map display
   B. Accessing logistical reports (LOGSTAT) located under the Routine tab in the FIPR menu
   C. Requesting a SITREP from subordinate units
   D. All the above
4. TF COAs can be changed by:
   A. Clicking a desired course of action (COA) radio button in the Command Directives menu, then clicking the execute button
   B. Clicking, dragging, and releasing combat resource icons in the map display
   C. Developing and sending fragmentary orders (FRAGO) in the FIPR menu
   D. All of the above

5. ***Approximate*** the TF Level fuel status by percentage and color convention using the following data (TF full authorized UBL for Fuel = 14,676 Gal):

Formula: $\dfrac{\text{Sum Total of Remaining Resource}}{\text{Authorized UBL}}$

TM A current fuel status = 3,540 Gal

TM B current fuel status = 4,500 Gal

TM C current fuel status = 2,580 Gal

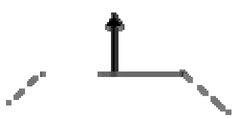
TM D current fuel status = 1,620 Gal

Mortars current fuel status = 280 Gal

Scouts current fuel status = 100 Gal

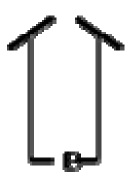
A. 75% / Amber
B. 68% / Red
C. 86% / Green
D. None of the above

6. The following graphic control measure represents:



A. Support by fire
B. Attack by fire
C. Breach
D. None of the above

7. The following graphic control measure represents:



A. Breach
B. Direction of attack
C. Blocking position
D. None of the above

8. The following graphic control measure represents:

A. Attack by fire

B. Breach

C. Support by fire

D. None of the above

9. The following graphic control measure represents:

A. Coordination point

B. Decision Point

C. Check point

D. None of the above

10. Calculate the friendly to enemy force ratio (ex. 3:1) using the following data:

$$\textbf{Formula} \text{ ------->} \quad \frac{\text{Total \# Alive Friendly Tanks \& BFVs}}{\text{Total \# Alive + Anticipated Additional T-72s \& BMPs}}$$

Remaining friendly vehicle strength – 24 x Tanks; 20 x BFVs

Remaining known / alive enemy vehicle strength – 1 x T-72; 6 x BMPs

Unidentified, but anticipated (i.e., template) additional enemy vehicles – 1 x T-72s; 3 x BMPs

A. 5:1

B. 2:1

C. 4:1

D. None of the above

11. Current TF combat power (i.e., SLANT) can be determined by:

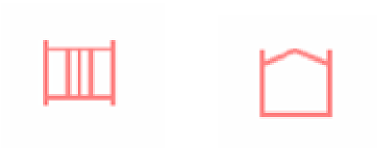
A. Requesting a SITREP from subordinate units

B. Accessing each subordinate unit's most current logistical report (LOGSTAT) in the FIPR menu, then calculating the quantities of operational vehicles by type

C. TF combat power cannot be determined

D. None of the above

12. The below icons represent:



A. Mortar System / Howitzer

B. Tank / Infantry Fighting Vehicle

C. Anti-Tank Rocket Launcher / Building

D. None of the above

13. The below icons represent:

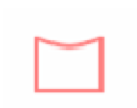
A. Mortar System / Anti-Tank Rocket Launcher (RPG)

B. Howitzer / Anti-Aircraft Gun

C. Tank / HMMWV

D. None of the above

14. The below icon with ***red*** *diamond background* represents:



A. Unknown Wheeled Vehicle

B. Infantry Fighting Vehicle

C. VBIED

D. None of the above

APPENDIX F. RAPTOR STUDY FEEDBACK SURVEY

Directions: The following statements concern your perceptions about the different displays, options, tools, etc provided by the RAPTOR interface. Please rate the strength of your agreement for each statement below by placing a check mark next to the applicable number on the scale. Please provide any additional comments that will assist researchers in determining the overall ability of RAPTOR's interface design to effectively assist user's as they execute the C2 of tactical operations.

1. The individual resource bar chart color codes used in the Friendly Resource Display enables rapid comprehension of unit combat effectiveness:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. The Force Ratio Display facilitates decision-making by enabling users to quickly determine which force (friendly or enemy) has a superior advantage:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

3. The Control Tree enables users to quickly determine friendly resource statuses at finer or courser levels of detail (e.g., Platoon level status vs. Battalion level status):

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

4. The course of action (COA) buttons assists with decision-making by enabling users to rapidly access and view alternate actions friendly forces can execute if required:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

5. Information provided in the Synchronization Matrix enables users to anticipate future friendly force activities by time, phase, and event:

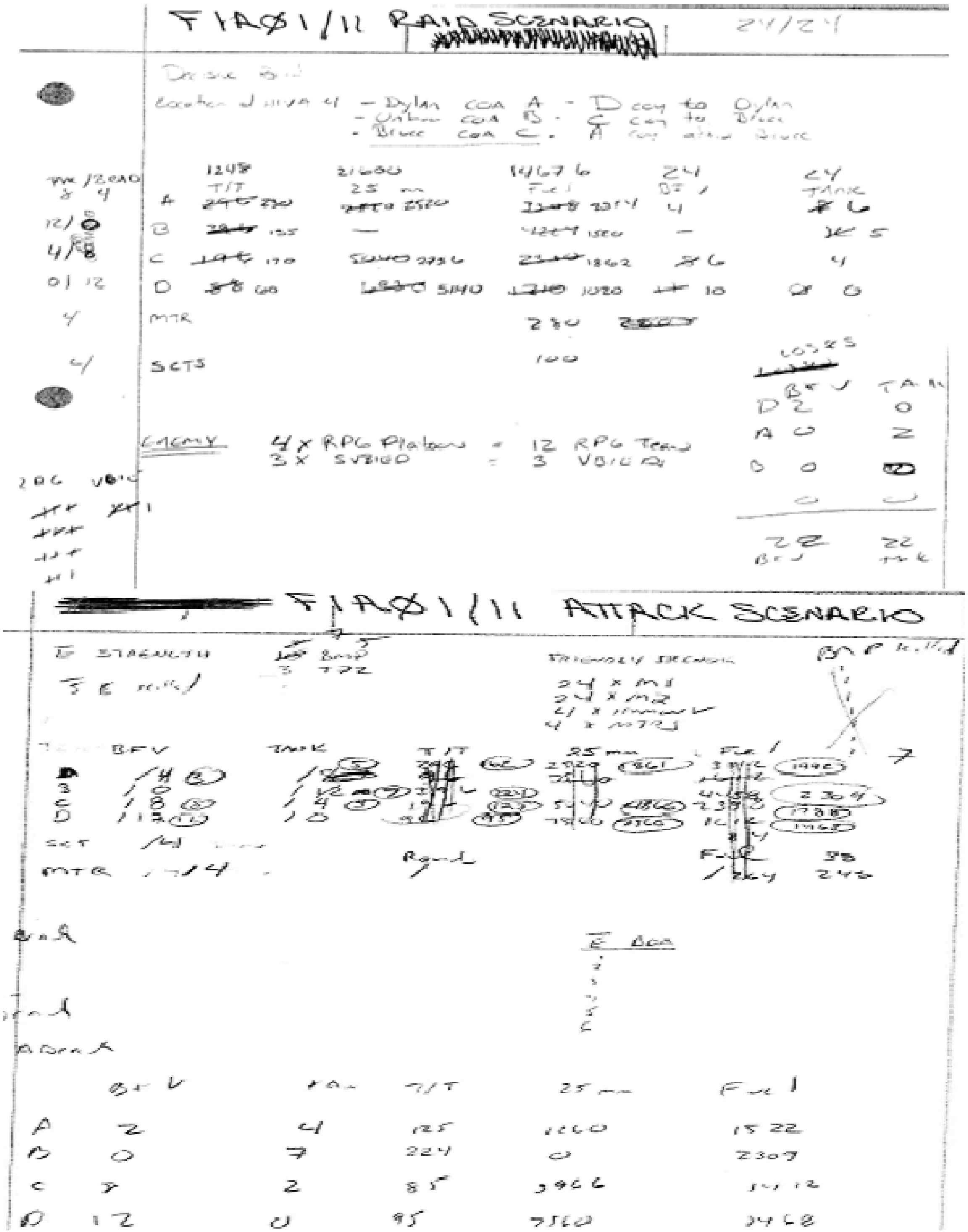
1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

6. The Enemy Resource Chart reduces uncertainty by enabling users to quickly determine enemy strength and combat effectiveness:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

7. Other observations concerning the effectiveness or usefulness of any of the interface displays, tools, options, etc. that enable, assist, or impede the user’s ability to conduct C2:

APPENDIX G. BASELINE USER IMPROMPTU AIDS


FIAØ1/11 RAID SCENARIO 24/24

Decisive Bid

ENEMY 4 x RPG Platoons = 12 RPG Teams
3 x SV BIED = 3 VBIEDs

	T/T	25 mm	Fuel	BFV	TANK
A	290	2520	2014	4	6
B	155	—	1500	—	5
C	170	2956	1862	6	4
D	60	5140	1020	10	0

MTR 280

SCTS 100

LOSSES

	BFV	TANK
D	2	0
A	0	2
B	0	0
	22 BFV	22 TNK

FIAØ1/11 ATTACK SCENARIO

FRIENDLY STRENGTH
24 x M1
24 x M2
4 x MTRS

E BOA

	BFV	TAN	T/T	25 mm	Fuel
A	2	4	125	1160	1522
B	0	7	224	0	2307
C	7	2	85	3966	1412
D	12	0	95	7560	2468

FIA02/12 RAID SCENARIO

	A	B	C	D	SCTS	MTR	
M1	~~8~~ 6	~~12~~ 5	4	0			
M2	4	0	~~8~~ 6	~~12~~ ~~11~~ 10			
SCTS					4		
MRTR						4	
T/T	~~215~~ 230	~~345~~ 135	~~145~~ 170	~~88~~ 60			1248
25 mm	2520		~~5040~~ 3034	~~6450~~ 4850			21,600
Fuel	~~3408~~ 2354	~~4224~~ 1520	~~3380~~ 1862	~~1210~~ 1020	100	280	14,676

FIA02/12 ATTACK SCENARIO $\frac{35}{3}$

	A	B	C	D	SCTS	MORTAR	
M1	~~8~~ 3	~~12~~ ~~7~~ 5	~~4~~ 3				
M2	~~4~~ 2		8	12		~~4~~	
SCTS					~~4~~ 2		
MORTAR						4	
T/T	~~245~~ 97	~~345~~ ~~302~~ 145	~~145~~ ~~143~~ 127	~~95~~ 95			1248
25 mm	~~2520~~ 1115		~~5040~~ ~~5041~~ 4895	7520			21,600
Fuel	~~3512~~ ~~4229~~ 1224	~~4408~~ ~~2302~~ 1535	~~2386~~ ~~1739~~ 1689	~~1612~~ 1468	~~84~~ 38	~~264~~ ~~248~~ 188	14,676

F1AØ3/13 ATTACK SCENARIO

	BFV	Tank	Mortar	Survey
C	4	2	4	2
A	2	3		
D	12			
B		7		

	TT	DS	Fuel	BFV	Tank
C	128	3757	1510	6	2
A	92	1266	1216	2	3
B	220	Ø	2330	Ø	7
	95	7560	1468	12	Ø
	535	12428	6524	20	13

	TT	DS	Fuel	BFV	Tank
C	79	3671	1178	6	2
A	92	1086	1216	2	3
B	220	Ø	2330	Ø	7
D					
MTR			188		

Svt

	BFV	T	D	M
A				
B	Ø			
C				
D			4	0
S				
M			6	4

11 RPG west

12 APCs
3 destroyed

2 UH60
1 Destroyed

(COA B)
OBJ Bruce if no AVs 10

A 13(COA C) if we see AVs IVO OBJ Bruce

	TT	DS	Fuel	BFV	Tanks	
A	230	2520	2554	4	6	
B	135	Ø	1520	0	5	
C	166	2562	1867	6	4	
D	60	5146	1030	10	Ø	
S						4
M						4
				20	15	

657

F1AØ3/13 RAID SCENARIO

Red

3 T-72
10 BMP
13 TOTAL

BLUE
24 T
24 T
4 M
21 HAWVS

Scouts
work
UP ...

120 134
25 248
F
1068 4

Sm ... 4 5:58
MOR 4 5:58
C 8/4 7:02

6 = T/T 186
25 5040
F 2389
B 8
T 4

T/T 500
25 min 11,224
F 6,351
B 18
T 12

	A	B	C	D	S	M
T	95	221	87	95	5	
	514		350	7560		248
25	1107	2327	1163	1468 38		
F		0	5	12		
B	1	7	2	6		
T	3					

	A	B	C	D	S	M
D	4/8	9/10	8/3	12/6	2	4

Smt 5 BMP
A 2 BMP
B 1 BMP
D 1 BMP

B 24
T 23
47

2 4
53
10

B C
0/7 5/2
2/3

A	B	C	D	S	M
1/3	0/7	5/2	12/0	2	4

FIAØ4/12 ATTACK SCENARIO

FIAØ4 RAID SCENARIO

	SC	M	A	B	C	D
T/T			98	159	134	95
25			1861		3780	7560
F	38	248	1335	1665	1514	1468
B			3		6	12
T			3	5	3	

F2MØ1/11 ATTACK SCENARIO

EN BMP: (10) ~~||||~~ ~~||||~~

TANK: (3)

	T/T	25	Fuel	B	T
A	296	2520	3512	4	8
B	396	—	4488	–	12
C	196	5040	2388	8	4
D	96	7560	1612	12	
MTR			264		
SCT	78	70	84 84%	24	24

+ 21 Nov 01/11 ATTACK SCENARIO

	T/A	25	F	D	T
A	98	1260	1215	2	3
B	224	—	2305	—	7
C	127	4750	1722	8	3
D	90	7560	1468	12	Ø
MTR			248		
SCT	43	63	38 48	92	54
	1248	21606	14676	24	24

A	98	1260	1215	2	3
B	224	—	2305	—	7
C	10	2852	600	6	0
D	95	7560	1468	12	—
MTR			188	20	10
SCT	34	54	38 40	83	41

F2M01/11 RAID SCENARIO

	T/+	25	F	B	T
A	230	2520	2354	4	6
B	135	0	1520	0	5
C	170	3084	1862	6	4
D	60	5140	1020	10 [illegible]	[illegible]
			280		
MTR			100		
SCT	B 47	B 49	B 48	B [illegible]	62 R

RPG of 12	~~||||~~ ~~||||~~
SVBIED of 3	||

+2MØ1/11 RAID SCENARIO

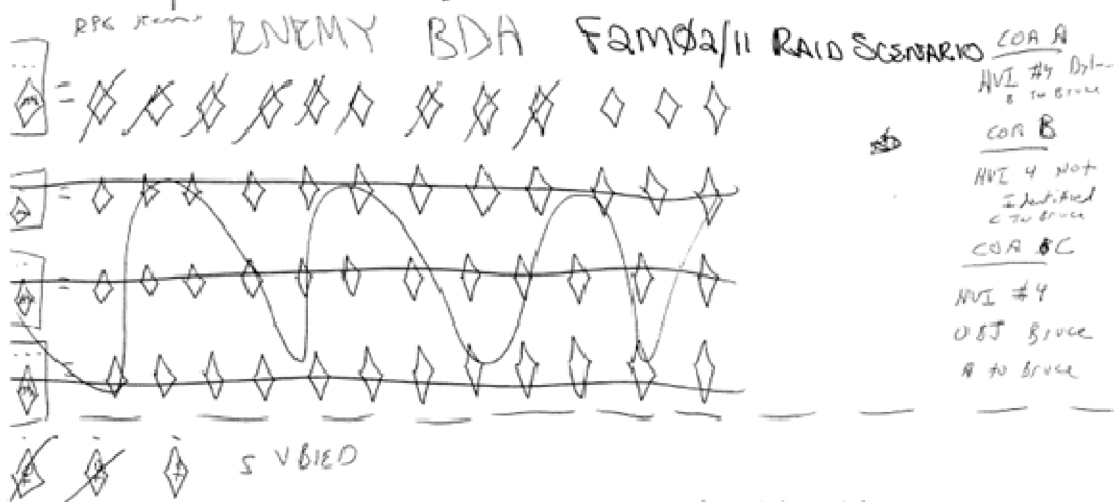
12 x RPG Tms

! 3 x SVBIED (MXCON) ②

.1 x MTR Sqdn

	+	2F	F	D	T
A	296	2520	3308	4	8
B	396	Ø	4224	0	12
C	196	5040	2380	8	4
D	88	6930	1210	11	0
			280		
			100		
	976	14490	11502	23	24
	78	67	78%	9.	
				G	G

A	230	2520	2354	4	/ 6
B	396	~~10~~	4224	0	/ 12
C	196	5040	238	8	4
D	60	5140	1020	10	/ 0
			280		
	70	59	100		
			55%		



62 82 76 41 49

F2M02/11 RAID SCENARIO

A	B	C	D	M		
62 R	82 A	76 A	41 S	49 B	62	R
70 A		70 R	67 R		R	
49 B	69 R	69 R	48 B	73 A	R	
100 G		100 G	83 A	100 G	G	
75 A	100 G	100 G			G	

EN T2M02/12 ATTACK SCENARIO

3/2

COA P4

A TM D FPOL WITM B assault Dallas

B TM D FPOL TM C assault OBJ Dallas

C TM D FPOL TM A assault OBJ Dallas

Assault objective COA P3

A TM D follows and supports TM B Boston

B TM D Follows/supports TM C to Dallas

C TM D Follows/supports TM A to Atlanta

Breach

COA 5 & 2

A TM B Brea... TM D follows B to Killer

B TM C establishes breach TM D follow TM C south toward OBJ Killer

C TM A establishes the initial breach TM D follows A North

T2M02/12 ATTACK SCENARIO

A	T T T T T B B B B
B	T T T T T T
C	T T T T B B B B B B B B
D	B B B B B B B B B B B B
M	120 120 120 120 22/13/2/4
SCT	HMV HMV HMV HMV 22/15/2/4

A B × 3
A
– R

F2M02/12 ATTACK SCENARIO LOG

A B
B B
C
D
M
S

A B
A
R

B B

C B
G
A

R

B × 2
– B
C B × 2
A
G
A

D R
A
R
G
B × 2
R
B × 2

F2M03/13 ATTACK SCENARIO

SC	D	A	B	C	M	
BL	92	157	222	84		1248
	7560	1621	~~2205~~	3271		21600
38	1469	1491	2308	1398	188	14676
	12	3		8		23/ 24
		5	7	2		14/ 24

F2M03/13 ATTACK SCENARIO

c M s

196 96 396 296 984

5040 7560

2388 264 84 1612 4490 2520 15120

3514 12352

8

4

HMV -2

A	B	C	D	Sct	Mort	
157	222	169	92			640
1629	-	5011	7560			
1991	2308	2124	1469	38	248	
3	-	8	12	[illegible]		
5	7	4				
				2	4	

72

BMP 2 LHT 7

24 M2
24 M1
4 Mort
4 HMMWV

9 1
2 1 F2M03/13 RAID SCENARIO

HQ

4 x SKPG HK most likely

3 SUBIED F most dang

9

	D	B				
TT	88	396	196	286	976	.78
25	6930		5040	2520	14490	.67
Fuc	1210	4224	2380	3308	11122	.757
BFV	11		8	4		
TK		12	4	8		

	D	C	B	A	4 S	M
M1		4	12	6		
M2	10	8		4		
Mort					4	4

198

		D	A	B	C		
882	TT	60	230	396	196		
12700	25	5140	2520		5040		
10358	Fuel	1020	2354	4224	2380	280	100

	See	Kill	
BMP	All/10		10
T-72	III	III	3

1:29
7:06
MDCOA

$\frac{48}{10} \rightarrow 5$

	T/T	25	F	BFV	Tank
A	93	1281	1324	3	3
B	221		2306		7
C	34	2628	788	5	1
D	94	2560	1612	12	0
MHr			188		
Sct			84		

Vch
4
2

1248	21600	14676	24	24
~~78%~~	~~70%~~	~~84%~~	~~100~~	~~100~~
32%	61%	49%	92%	54%
B	R	B	G	R
35%	53%	43%	85%	46%
B	R	B	A	B

F2M04/14 ATTACK SCENARIO

Fam Ø4/14 RAID SCENARIO

RPG		12
VBIED		3

	T/T	25	F	BRV	Tanks
A	296	2520	3308	4	8
B	396		4224		12
C	196	5040	2380	8	4
D	88	6830	1210	11	1
[illegible]	[illegible]		280		
Sct	[illegible]	180	100		2 1
				23	
	1248	21600	14676	24	24
	78%	67%	79%		
	A	R	A	G	G

F2M Ø4/14 RAID SCENARIO 44/9

RPG	~~HHT~~ ~~HHT~~	12
VBIED	II	3

? 22
22
44

	T/I	25	C	BFV	T
A	230	2520	2354	4	6
B	237 ~~390~~	0 ~~4~~	2464 ~~4264~~	0 ~~8~~	8 ~~12~~
C	163 ~~496~~	2280 ~~5040~~	1755 ~~2380~~	5 ~~8~~	4 ~~4~~
				18	
D	60	4850	1020	10	
Mtr			280		
Sct			100		

B	B	B	A	A
55%	45%	54%	79%	75%
1242	21600	14676	24	24
~~71%~~	~~57%~~	~~77%~~	~~91%~~	~~91%~~
			~~6~~	~~6~~

F2M04/14 RAID SCENARIO

R	~~IIII~~ ~~IIII~~ II	12	2
V	II	13	1

	T/T	25	S	B	T
A	T/				
B					
C					
D					
M					
S					
	9248	21600	14676	24	28

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Adams, M. J., Tenney, Y. J., & Pew, R. W. (1995). Situation awareness and the cognitive management of complex systems. *Human Factors, 37*(1), 85.

Aldag, R. J., & Power, D. J. (1986). An empirical assessment of computer-assisted decision analysis. *Decision Sciences, 17*(4), 572.

Arden, D. B. (1996). *Command dysfunction: Minding the cognitive war*. Master's Thesis, School of Advanced Airpower Studies, Maxwell Air Force Base, AL. Retrieved 11/08 from http://www.maxwell.af.mil/au/awc/awcgate/saas/dahl_ab.pdf.

Bennett, K. B., Payne, M., & Walters, B. (2005). An evaluation of a "time tunnel" display format for the presentation of temporal information. *Human Factors, 47*(2), 342.

Bennett, K. B., Posey, S. M., & Shattuck, L. G. (2008). Ecological interface design for military command and control. *Journal of Cognitive Engineering and Decision Making, 2*(4), 349-385.

Bennett, K. B., & Zimmerman, J. (2001). A preliminary investigation of the time tunnels display design technique. *Displays, 22*(5), 183.

Blackwell, J. (2007). The cognitive domain of war. *The International Economy, 21*(3), 33.

Booher, H. R. (2003). *Handbook of human systems integration.* Hoboken, NJ: Wiley-Interscience.

Bushey, D. A., & Forsyth, M. J. (2006). The recognition-primed decision model: An alternative to the MDMP for GWOT. *FA Journal, 11*(1), 10.

Defense Advanced Research Project Agency. (2009). Command post of the future (CPOF). Retrieved 04/09 from http:// *www.darpa.mil/sto/strategic/cpof.html.*

Department of the Army. (1993). *A leader's guide to after-action reviews. Training Circular 25-20*. Washington, DC: U.S. Government Printing Office.

Department of the Army. (1997). *Staff organization and operations. Field Manual 101-5*. Washington, DC: U.S. Government Printing Office.

Department of the Army. (1999). *U.S. Army report and message formats. Field Manual 101-5-2*. Washington, DC: U.S. Government Printing Office.

Department of the Army. (2003). *Mission command: Command and control of army forces. Field Manual 6-0*. Washington, DC: U.S. Government Printing Office.

Department of the Army. (2004). *Operational terms and graphics. Field Manual 1-02*. Washington, DC: U.S. Government Printing Office.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors*, *37*(1), 65.

Endsley, M. R., & Garland, D. J. (2000). *Situation awareness: Analysis and measurement*. Mahwah, NJ: Lawrence Erlbaum Associates.

Flach, J. M. (1995). Situation awareness: Proceed with caution. *Human Factors*, *37*(1), 149.

Garstka, J., & Alberts, D. (2004). *Network centric operations conceptual framework*. Vienna, VA: Evidence Based Research, Inc.,. Retrieved 11/08 from http://www.oft.osd.mil/initiatives/ncw/docs/20AUG04%5FVersion%202-0%20Network%20Centric%20Operations%20Conceptual%20Framework.doc.

Hall, J. D. (2000). Decision making in the information age: Moving beyond the MDMP. *Field Artillery,* (5), 28.

Hamm, R. M. (1988). Moment-by-moment variation in experts' analytic and intuitive cognitive activity. *Systems, Man and Cybernetics, IEEE Transactions on, 18*(5), 757-776.

Hazen, M. G., Burton, R., Klingbeil, R., Sullivan, K., Fewell, M., Grivell, I., Philp, C., & Marland, P. (2003). The analysis of network centric maritime interdiction operations (MIO) using queueing theory. *Eighth International Command and Control Research and Technology Symposium*.

Kemmerer, K. E. (2008). *Tactical decision making under categorical uncertainty with applications to modeling and simulation.* Master’s Thesis, Naval Postgraduate School, Monterey, CA.

Klein, G. (1993). A recognition-primed decision (RPD) model of rapid decision making. *Decision making in action: Models and methods.* Westport, CT, U.S.: Ablex Publishing.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (2003). Macrocognition. *Intelligent Systems, IEEE*, *18*(3), 81-85.

Klein, G. (2008). Naturalistic Decision Making. *Human Factors, 50*(3), 456-460.

Libicki, M. C., & Johnson, S. E. (1996). *Dominant battlespace knowledge* (Rev ed.). Washington, D.C.: National Defense University Press.

Lipshitz, R., Klein, G., Orasanu, J., & Salas, E. (2001). Taking stock of naturalistic decision making. *Journal of Behavioral Decision Making, 14*(5), 331.

McGuinness, B. (2004). *Quantitative analysis of situational awareness (QUASA): Applying signal detection theory to True/False probes and self-ratings*. Bristol, U.K.: BAE Systems Advanced Technology Centre.

Miller, N. L., & Shattuck, L. G. (2008). *Human systems integration.* Retrieved 09/05, 2008, from http://www.nps.edu/or/hsi/.

Phister, J.,Paul W., Busch, T., & Plonisch, I. G., AIR FORCE RESEARCH LAB WRIGHT-PATTERSON AFB OH INFORMATION DIRECTORATE. (2003). *Joint synthetic battlspace: Cornerstone for predictive battlespace awareness.* Retrieved 09/08 from http://handle.dtic.mil/100.2/ADA467439.

Potter, S. S., Elm, W. C., Roth, E. M., & Woods, D. D. (2001). *The development of a computer-aided cognitive systems engineering tool to facilitate the design of advanced decision support systems*. No. Report Number(s): AFRL-HE-WP-TR-2001-0125 XC-AFRL-HE-WP).

Rasmussen, J. (1992). A taxonomy for analysis of cognitive work. *Human Factors and Power Plants, 1992. Conference Record for IEEE Fifth Conference on, 7*(11), 41-50.

Rasmussen, J., & Vicente, K. J. (1990). Ecological interfaces: A technological imperative in high-tech systems? *International Journal of Human-Computer Interaction, 2*(2), 93.

Read, D. W. (2007). *The Abbott and Costello effect: Who's on what, and what's where when? A human-centered method to investigate network centric warfare systems.* Master's Thesis, Naval Postgraduate School, Monterey, CA.

Ross, K. G., Klein, G. A., Thunholm, P., Schmitt, J. F., & Baxter, H. C. (2004). The recognition-primed decision model. *Military Review, 84*(4), 6.

Smith, E. A. (2006). Effects-based operations: Applying network centric warfare in peace, crisis, and war. U.S. DoD Cooperative C4ISR Research Project. Retrieved 10/08 from http://www.securitychallenges.org.au /SC%20Vol%202%20No%201/vol%202%20no%201%20Smith.pdf.

Smith, G. F. (1989). Representational effects on the solving of an unstructured decision problem. *Systems, Man and Cybernetics, IEEE Transactions on, 19*(5), 1083-1090.

Shapiro, J. (1999). *Strategic appraisal; the changing roles of information in warfare* No. MR-1016-AF.

Shattuck, L. G., Graham, J. M., Merlo, J. L., & Hah, S. (2000). Cognitive integration: A study of how decision makers construct understanding in evolving contexts. *Human Factors Engineering Society, 2000. Proceedings of the Human Factors Society Annual Meeting, 44*(1), 116-119.

Shattuck, L. G., & Miller, N. L. (2006). Extending naturalistic decision making to complex organizations: A dynamic model of situated cognition. *Organization Studies, 27*(7), 989.

Shattuck, L. G. (2007). *Decision Making.* Unpublished manuscript.

Talcott, C. P., Bennett, K. B., Martinez, S. G., Shattuck, L. G., & Stansifer, C. (2007). Perception-action icons: An interface design strategy for intermediate domains. *Human Factors, 49*(1), 120.

United States & Dept. of Defense. (2001a). *Network centric warfare department of defense report to congress*. Washington, DC: The Department.

United States & Dept. of Defense. (2001b). *Network centric warfare department of defense report to congress*. Washington, DC: The Department.

Van Orden, K.F. (2001). *Monitoring moment-to-moment operator workload using task load and system-state information.* SSC San Diego Technical Report 1864. Space and Naval Warfare Systems Center, San Diego, CA.

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *Systems, Man and Cybernetics, IEEE Transactions on, 22*(4), 589-606.

Wickens, C. D. (2008). Situation awareness: Review of Mica Endsley's 1995 articles on situation awareness theory and measurement. *Human Factors, 50*(3), 397.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, VA

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA

3. Lawrence G. Shattuck
   Naval Postgraduate School
   Monterey, CA

4. Nita L. Miller
   Naval Postgraduate School
   Monterey, CA

5. Kevin B. Bennett
   Wright State University
   Dayton, OH

6. LTC James M. Merlo
   United States Military Academy
   West Point, NY

7. Michael D. Matthews
   United States Military Academy
   West Point, NY

8. LTC David Hudak
   TRAC – MTY
   Monterey, CA